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**System access and synchronization methods for MIMO OFDM communications systems and physical layer packet and preamble design**

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A method and apparatus are provided for performing acquisition, synchronization and cell selection within an MIMO-OFDM communication system. A coarse synchronization is performed to determine a searching window. A fine synchronization is then performed by measuring correlations between subsets of signal samples, whose first signal sample lies within the searching window, and known values. The correlations are performed in the frequency domain of the received signal. In a multiple-output OFDM system, each antenna of the OFDM transmitter has a unique known value. The known value is transmitted as pairs of consecutive pilot symbols, each pair of pilot symbols being transmitted at the same

subset of sub-carrier frequencies within the OFDM frame.

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(71) 出願人 390023157  
 ノーテル・ネットワークス・リミテッド  
 カナダ国 オンタリオ州、エル6ティ  
 5ビー6、ブランプトン ジーエムエス  
 036/エヌオー/151、ディクシー・  
 ロード 8200、スイート100  
 (74) 代理人 100089118  
 弁理士 酒井 宏明  
 (72) 発明者 ミア、チャンリー  
 カナダ国、ケー2エム 2ダブリュ5 オ  
 ンタリオ、カナダ、ボン エコ クレセン  
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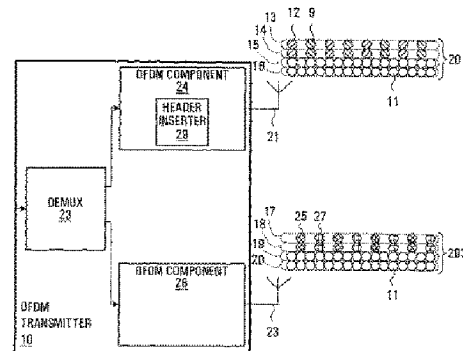
(54) 【発明の名称】 マルチ搬送波CDMAシステムにおける同期化

(57) 【要約】

【課題】MIMO-OFDM通信システム内で取得、同期およびセル選択を行なうための方法および装置が提供される。

【解決手段】検索ウィンドウを決定するために粗同期が行なわれる。その後、信号サンプルのサブセット間の相関を測定するために微同期が行なわれる。信号サンプルのうちの最初の信号サンプルは、検索ウィンドウ内にあり、周知の値である。相関は、受信信号の周波数領域で行なわれる。マルチ出力OFDMシステムにおいて、OFDM送信機の各アンテナは、固有の周知の値を有する。周知の値は、連続するパイロットシンボルの対として送信され、パイロットシンボルの各対は、OFDMフレーム内の副搬送波周波数の同じサブセットで送信される

【選択図】図6



⊙-DEDICATED PILOT CHANNEL FOR ANT#1  
 ⊙-DEDICATED PILOT CHANNEL FOR ANT#2  
 ⊙-COMMON SYNCHRONIZATION CHANNEL FOR ANT#1  
 ⊙-COMMON SYNCHRONIZATION CHANNEL FOR ANT#2

**【特許請求の範囲】****【請求項 1】**

複数のアンテナのそれぞれにおいてヘッダ OFDM シンボルの副搬送波が副搬送波の非連続なセットに分割されるというヘッダシンボルフォーマットを送信するようになっており、  
各アンテナは、副搬送波の各セット上でのみ前記ヘッダ OFDM シンボルを送信する、MIMO-OFDM 送信機。

**【請求項 2】**

N 個のアンテナが存在し、N 個の副搬送波によって分離された副搬送波の異なるセットが前記複数のアンテナのそれぞれに対して割り当てられる、請求項 1 に記載の MIMO-OFDM 送信機。 10

**【請求項 3】**

前記ヘッダシンボルは、前記複数のアンテナのそれぞれにおいて、専用パイロットチャネル副搬送波上に、多重化された専用パイロットチャネルを含むとともに、共通同期チャネル副搬送波上に、共通同期チャネルを含む、請求項 1 に記載の MIMO-OFDM 送信機。

**【請求項 4】**

前記ヘッダ OFDM シンボルは、前記複数のアンテナのそれぞれにおいて、多重化されたブロードキャスト副搬送波を更に含む、請求項 3 に記載の MIMO-OFDM 送信機。

**【請求項 5】**

プレフィックスと、該プレフィックスの後に続き且つ前記ヘッダ OFDM シンボルフォーマットを有する 2 つの同一の OFDM シンボルとを有するプリアンブルを送信するようになっている、請求項 1 に記載の MIMO-OFDM 送信機。 20

**【請求項 6】**

前記プレフィックスは、前記 2 つの同一の OFDM シンボルの巡回拡張子である、請求項 5 に記載の MIMO-OFDM 送信機。

**【請求項 7】**

前記専用パイロットチャネル副搬送波は、効率的な BTS 識別を行なうことができる BTS 固有のマッピングされた複合シーケンスを有する、請求項 3 に記載の MIMO-OFDM 送信機。 30

**【請求項 8】**

前記共通同期チャネルは、高速で且つ正確な初期取得を行なえるように設計されている、請求項 3 のいずれか一つに記載の MIMO-OFDM 送信機。

**【請求項 9】**

前記共通同期チャネルは、粗同期および微同期のために使用され、前記専用パイロットチャネルは、微同期のために使用される、請求項 3 に記載の MIMO-OFDM 送信機。

**【請求項 10】**

前記共通同期チャネルは、1 つの送信機の送信アンテナ毎に異なるが通信ネットワーク内の様々な送信機の各送信アンテナに共通する複合シーケンスを送信するために使用される、請求項 3 に記載の MIMO-OFDM 送信機。 40

**【請求項 11】**

前記プリアンブルから始まる OFDM フレームを送信するようになっており、前記 OFDM フレームは、各 OFDM フレーム内の残りの OFDM シンボルにわたって分散パイロットを有する、請求項 1 に記載の MIMO-OFDM 送信機。

**【請求項 12】**

前記プリアンブル中、N 個の送信アンテナのそれぞれにおいて、専用パイロットチャネル副搬送波が送信され、共通同期チャネル副搬送波が送信され、ブロードキャストチャネル副搬送波が送信される、請求項 1 に記載の MIMO-OFDM 送信機。

**【請求項 13】**

前記プリアンブルの OFDM シンボルの副搬送波は、所定の順序で配置される {N 個の送 50

信アンテナのそれぞれにおける専用パイロットチャネル、N個の送信アンテナのそれぞれにおける共通同期チャネル副搬送波から成る繰り返しシーケンスとして編成される、請求項3に記載のMIMO-OFDM送信機。

【請求項14】

前記プリアンプルのOFDMシンボルの副搬送波は、所定の順序で配置される {N個の送信アンテナのそれぞれにおける少なくとも1つの専用パイロットチャネル副搬送波、N個の送信アンテナのそれぞれにおける少なくとも1つの共通同期チャネル副搬送波、少なくとも1つのブロードキャストチャネル副搬送波} から成る繰り返しシーケンスとして編成される、請求項4に記載のMIMO-OFDM送信機。

【請求項15】

ヘッダOFDMシンボルの副搬送波が複数のアンテナのそれぞれにおいて副搬送波の非連続なセットに分割されるというヘッダシンボルフォーマットを受信するようになっており、

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各アンテナは、副搬送波の各セット上でのみ前記ヘッダOFDMシンボルを送信する、MIMO-OFDM受信機。

【請求項16】

N個の送信アンテナから受信するようになっており、N個の副搬送波によって分離された副搬送波の異なるセットが複数の各送信アンテナに対して割り当てられる、請求項15に記載のMIMO-OFDM受信機。

【請求項17】

前記ヘッダOFDMシンボルは、前記複数の送信アンテナのそれぞれにおいて、多重化された専用パイロットチャネル副搬送波と共通同期チャネル副搬送波とを含む、請求項15に記載のMIMO-OFDM受信機。

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【請求項18】

前記ヘッダOFDMシンボルは、前記複数のアンテナのそれぞれにおいて、多重化されたブロードキャスト副搬送波を更に含む、請求項17に記載のMIMO-OFDM受信機。

【請求項19】

プレフィックスと、該プレフィックスの後に続き且つ前記ヘッダOFDMシンボルフォーマットを有する2つの同一のOFDMシンボルとを有するプリアンプルを受信するようになっている、請求項15に記載のMIMO-OFDM受信機。

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【請求項20】

前記専用パイロットチャネルは、BTS固有のマッピングされた複合シーケンスを有し、本MIMO-OFDM受信機は、該専用パイロットチャネルに基づいてBTS識別を行なうようになっている、請求項15に記載のMIMO-OFDM受信機。

【請求項21】

前記専用パイロットチャネルは、BTS固有のマッピングされた複合シーケンスを有し、本MIMO-OFDM受信機は、該専用パイロットチャネルに基づいてBTS識別を行なうようになっている、請求項19に記載のMIMO-OFDM受信機。

【請求項22】

前記ヘッダOFDMシンボルは、複数の送信アンテナのそれぞれにおいて、多重化された専用パイロットチャネル副搬送波と、共通同期チャネル副搬送波とを含み、本MIMO-OFDM受信機は更に、互いに同一の連続するOFDMシンボル間で相関ピークを探すことにより、前記共通同期チャネルにおいて粗同期を行なうようになっている、請求項21に記載のMIMO-OFDM受信機。

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【請求項23】

前記共通同期チャネル副搬送波及び／又は前記専用パイロットチャネル副搬送波に基づいて微同期を更に行なうようになっている、請求項22に記載のMIMO-OFDM受信機。

【請求項24】

パケットデータフレーム構造を送信するようになっている送信機であって、

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ネットワークの同期期間に対応する長さを有するスーパーフレームを備え、  
 前記スーパーフレームは、複数の無線フレームを含み、  
 各無線フレームは、適応コーディング及び変調期間に対応する複数のTPS（送信パラメータ信号）フレームを含み、  
 各TPSフレームは、エアーインタフェーススロットサイズに対応する複数のスロットを含み、  
 各スロットは複数のOFDMシンボルを含み、各OFDMフレームの最初のTPSフレームの最初のスロットの最初の2つのシンボルは、ヘッダOFDMシンボルとして使用される、送信機。

【請求項25】

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前記ヘッダOFDMシンボルは、該ヘッダOFDMシンボルの副搬送波が複数のアンテナのそれぞれにおいて副搬送波の非連続なセットに分割されるというヘッダOFDMシンボルフォーマットを有し、各アンテナは、副搬送波の対応するセット上でのみ前記ヘッダOFDMシンボルを送信する、請求項24に記載の送信機。

【請求項26】

前記ヘッダOFDMシンボルは、複数のアンテナのそれぞれにおいて、多重化された専用パイロットチャネル副搬送波を含むとともに、共通同期チャネル副搬送波を含む、請求項24に記載の送信機。

【請求項27】

前記ヘッダOFDMシンボルは、前記複数のアンテナのそれぞれにおいて、多重化されたブロードキャストチャネル副搬送波を更に含む、請求項24に記載の送信機。

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【請求項28】

スロット持続時間が変わることなく且つスロットよりも上のフレーム構造を変えることなく1スロット毎に異なる数のOFDMシンボルを送信することにより、複数の異なるモードで送信するようになっている、請求項24に記載の送信機。

【請求項29】

1スロット当たりのOFDMシンボルの数が増大するモードは、サンプリング周波数を変えることなくOFDMシンボル持続時間およびFFTサイズを短くすることにより実現される、請求項28に記載の送信機。

【請求項30】

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TPSフレーム毎にユーザの各組に対して送信するとともに、どのユーザがTPSフレーム全体を復調するべきかの信号をTPSフレーム毎に送信するようになっている、請求項24に記載の送信機。

【請求項31】

請求項24に記載の送信機によって送信されるOFDMフレームを受信して処理するようになっている受信機。

【請求項32】

OFDM受信機で同期を行なう方法であって、  
 少なくとも1つの受信アンテナのそれぞれで、受信信号をサンプリングして、時間領域サンプルの各セットを形成し、

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少なくとも1つの粗同期位置を決定し、

少なくとも1つの受信アンテナのそれぞれで、

a) 前記少なくとも1つの粗同期位置のうちの1つに関する複数の候補微同期位置のそれぞれにおいて、

i) 受信アンテナ毎に、候補微同期位置に対してFFTウィンドウを位置決めするとともに、FFTにより、時間領域サンプルを周波数領域成分の各セットに変換し、

ii) 前記少なくとも1つの送信アンテナそれぞれにおいて、周波数領域成分のセットから送信アンテナに対応する受信された各トレーニングシーケンスを抽出し、

iii) 送信アンテナ毎に、受信された各トレーニングシーケンスと周知の各送信トレーニングシーケンスとの間の相関を計算し、

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i v) 少なくとも1つの送信アンテナにおいて相関を組み合わせ、候補同期位置毎に全体の相関結果を形成し、  
b) 複数の相関値から微同期位置を決定し、  
少なくとも1つの受信アンテナからの複数の微同期位置を組み合わせ、全体の微同期位置とする、方法。

【請求項33】

粗同期位置は、受信アンテナ毎に決定されるとともに、各微同期位置を決定するために使用される、請求項32に記載の方法。

【請求項34】

粗同期位置が受信アンテナ毎に決定され、これらの位置のうちで最も早い位置が使用されて、全ての受信アンテナにおける微同期位置が決定される、請求項32に記載の方法。

【請求項35】

前記粗同期位置は、2つのOFDMシンボル持続時間にわたって時間領域サンプル間の相関ピークを探すことにより、少なくとも1つの受信アンテナにおいて時間領域で決定される、請求項33に記載の方法。

【請求項36】

少なくとも1つの受信アンテナからの複数の微同期位置を組み合わせ、全体の微同期位置とすることは、前記微同期位置のうちの最も早い位置を選択することを含む、少なくとも2つのアンテナを有するOFDM受信機で適用される、請求項32に記載の方法。

【請求項37】

受信信号をサンプリングして時間領域サンプルの各セットを形成することは、少なくとも3つのOFDMシンボル持続時間において行われ、  
少なくとも1つの粗同期位置を決定することは、2つのOFDMシンボル持続時間にわたって受けた前記時間領域サンプル間の相関ピークを探すことにより前記時間領域で粗同期を行ない、

a) 1つのOFDMシンボル持続時間を有する第1の期間中に受けた時間領域サンプルの第1のセットと、第1の期間の直ぐ次の第2の期間であってOFDMシンボル持続時間を有する第2の期間中に受けた時間領域サンプルの第2のセットとの間で計算された相関である複数の相関値のそれぞれを、前記第1の期間における複数の開始時間のそれぞれにおいて計算し、

b) 前記複数の相関値で最大となる粗同期位置を特定する、  
ことにより、粗同期位置を特定することを含む、請求項32に記載の方法。

【請求項38】

少なくとも1つの送信アンテナにおいて相関を組み合わせ、候補同期位置毎に全体の相関結果を形成することは、候補同期位置毎に少なくとも1つの送信アンテナにおける相関を一緒に乗算することを含む、請求項32に記載の方法。

【請求項39】

送信アンテナが1つで且つ受信アンテナが1つのシステムに対して適用される、請求項32に記載の方法。

【請求項40】

前記トレーニングシーケンスは、共通同期チャネル副搬送波上で受信される、請求項32に記載の方法。

【請求項41】

前記トレーニングシーケンスは、OFDMフレームプリアンプル中に受信される、請求項32に記載の方法。

【請求項42】

前記トレーニングシーケンスは、専用パイロットチャネル副搬送波上で受信される、請求項32に記載の方法。

【請求項43】

前記トレーニングシーケンスは、OFDMフレームプリアンプル中に受信される、請求項

4 2 に記載の方法。

【請求項 4 4】

少なくとも 1 つの受信アンテナと、  
前記少なくとも 1 つの受信アンテナ毎に設けられ、受信信号をサンプリングして、時間領域サンプルの各セットを形成するようになっている受信回路と、  
少なくとも 1 つの粗同期位置を決定するようになっている粗同期装置と、  
少なくとも 1 つの FFT と、少なくとも 1 つの相関器と、少なくとも 1 つのコンバイナとを備える微同期装置であって、少なくとも 1 つの受信アンテナのそれぞれで、  
a) 前記少なくとも 1 つの粗同期位置のうちの 1 つに関する複数の各候補微同期位置のそれぞれにおいて、

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i) 受信アンテナ毎に、前記候補微同期位置に対して FFT ウィンドウを位置決めするとともに、FFT により、前記時間領域サンプルを周波数領域成分の各セットに変換し、  
i i) 前記少なくとも 1 つの送信アンテナ毎に、周波数領域成分のセットから前記送信アンテナに対応する受信された各トレーニングシーケンスを抽出し、  
i i i) 送信アンテナ毎に、受信された各トレーニングシーケンスと周知の各送信トレーニングシーケンスとの間の相関を計算し、  
i v) 少なくとも 1 つの送信アンテナにおいて相関を組み合わせて、候補同期位置毎に全体の相関結果を形成し、

b) 複数の相関値から微同期位置を決定する、  
ようになっている微同期装置と、  
を備え、

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少なくとも 1 つの受信アンテナからの前記微同期位置を組み合わせて全体の微同期位置とするようになっている OFDM 受信機。

【請求項 4 5】

少なくとも 2 つの受信アンテナを有し、前記微同期位置のうちの最も早い位置を選択することにより、少なくとも 1 つの受信アンテナからの前記微同期位置を組み合わせて全体の微同期位置とするようになっている、請求項 4 4 に記載の OFDM 受信機。

【請求項 4 6】

候補同期位置毎に少なくとも 1 つの送信アンテナにおける相関を一緒に乗算することにより、少なくとも 1 つの送信アンテナにおいて相関を組み合わせて、候補同期位置毎に全体の相関結果を形成するようになっている、請求項 4 4 に記載の OFDM 受信機。

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【請求項 4 7】

共通同期チャネル副搬送波上で前記トレーニングシーケンスを受信するようになっている、請求項 4 4 に記載の OFDM 受信機。

【請求項 4 8】

専用パイロットチャネル副搬送波上で前記トレーニングシーケンスを受信するようになっている、請求項 4 4 に記載の OFDM 受信機。

【請求項 4 9】

微同期を行なう方法であって、  
少なくとも 1 つの受信アンテナのそれぞれで、少なくとも 1 つの送信アンテナ毎に受けた各周波数領域トレーニングシーケンスを含む OFDM シンボルを受信し、  
周知の周波数領域トレーニングシーケンスと受信した周波数領域トレーニングシーケンスとの間で最大相関を見つけることにより、周波数領域で微同期を行なうことを含む方法。

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【請求項 5 0】

微同期を可能にする信号を送信する方法であって、  
少なくとも 1 つの送信アンテナのそれぞれから、各周波数領域トレーニングシーケンスを含む OFDM シンボルを送信することを含む方法。

【請求項 5 1】

異なる周波数領域トレーニングシーケンスは各送信アンテナによって送信されるが、同じ

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周波数領域トレーニングシーケンスは、他の送信機の対応するアンテナによって送信される、請求項50に記載の方法。

【請求項52】

OFDM受信機でセル選択を行なう方法であって、  
 少なくとも1つの送信アンテナのそれぞれで、受信信号をサンプリングして、時間領域サンプルの各セットを形成し、  
 少なくとも1つの粗同期位置を決定し、  
 少なくとも1つの受信アンテナのそれぞれで、  
 a) 受信信号内の共通同期チャネル副搬送波から抽出された少なくとも1つの受信した共通同期シーケンスと、複数の送信アンテナのそれぞれに対応する共通同期シーケンスとの間で周波数領域相関を行なうことにより、複数の候補相関ピークを特定し、  
 b) 更なる処理のために、M個の最も強い相関ピークを選択し、  
 c) 各相関ピークで、時間領域サンプルを周波数領域成分に再変換するとともに、送信機固有の情報を含むパイロットチャネル副搬送波を処理して、各相関ピークに関連付けられた送信機を特定し、  
 d) そのように特定された各送信機においてC/Iまたは同様の値を決定し、  
 任意の少なくとも1つの受信アンテナにおいて決定されたC/Iが最も大きい送信機を選択する、  
 ことを含む方法。

【請求項53】

受信信号内の共通同期チャネル副搬送波から抽出された少なくとも1つの受信した共通同期シーケンスと、複数の送信アンテナのそれぞれに対応する共通同期シーケンスとの間で周波数領域相関を行なうことにより、複数の候補相関ピークを特定することは、  
 a) 前記少なくとも1つの粗同期位置のうちの1つに関する複数の各候補微同期位置のそれぞれにおいて、  
 i) 受信アンテナ毎に、前記候補微同期位置に対してFFTウィンドウを位置決めするとともに、FFTにより、前記時間領域サンプルを周波数領域成分の各セットに変換し、  
 ii) 少なくとも1つの送信機のそれぞれの送信アンテナによって送信された少なくとも1つの共通同期シーケンス毎に、前記周波数領域成分のセットから該送信アンテナに対応する受信された各トレーニングシーケンスを抽出し、  
 iii) 少なくとも1つの共通同期シーケンス毎に、受信された各共通同期シーケンスと周知の各共通同期シーケンスとの間の相関を計算し、  
 iv) 相関を組み合わせて、候補同期位置毎に全体の相関結果を形成し、  
 b) 相関の極大値である少なくとも1つのピークを相関において決定する、  
 ことを含む、請求項52に記載の方法。

【請求項54】

選択された送信機の前記微同期位置に基づいて、時間領域サンプルを周波数領域成分に再変換するとともに、その送信機における専用のパイロットチャネルに基づいて更なる微同期を行なうことを更に含む、請求項53に記載の方法。

【請求項55】

ヘッダシンボルの副搬送波が複数のアンテナのそれぞれにおいて非連続の副搬送波のセットに分割され、各アンテナは、副搬送波の各セット上でのみヘッダシンボルを送信し、前記ヘッダシンボルは、多重化されたパイロットチャネル副搬送波と、複数のアンテナのそれぞれにおいて共通同期チャネル副搬送波とを含み、前記フレームは、2つの同一のヘッダOFDMシンボルから始まり、そのヘッダOFDMシンボル中において、前記パイロットチャネル副搬送波のコンテンツが繰り返されるとともに、前記同期チャネル副搬送波のコンテンツが繰り返され、前記共通同期チャネル副搬送波は、1つの基地局のアンテナ毎に異なるが複数の基地局にわたって共通の複合シーケンスを搬送し、前記専用パイロットチャネル副搬送波のコンテンツは、少なくとも局所的に特定の基地局に固有のものである、ヘッダシンボルフォーマットを有するMIMO-OFDMフレームフォーマットに適用

される、請求項 5 4 に記載の方法。

【請求項 5 6】

送信機の切換えのため、そのように特定された送信機毎に、 $C/I$  または同様の値を所定の時間にわたって平均化し、その時間の最後に、現在選択されて送信されたものと異なる場合には、最も大きい平均  $C/I$  または同様の値を用いて前記送信機の送信機スイッチを起動させることを更に含む、請求項 5 2 に記載の方法。

【発明の詳細な説明】

【技術分野】

【0 0 0 1】

本発明はセルラー無線通信システムに関し、特に、OFDM または OFDM のような技術 10  
を使用したセルラー無線通信システム内でのシステムアクセス、物理層パケット、プリアンブル構造に関する。

【背景技術】

【0 0 0 2】

少なくとも 1 つの送信機と、少なくとも 1 つの受信機とを有する無線通信システムにおいて、受信機は、送信機によって送信された信号のタイミングを取得しなければならないとともに、受信した信号から情報を抽出できる前にそのタイミングに同期しなければならない。無線通信システム内で、基地局から送信される信号のタイミングは、一般にシステムタイミングと称される。

【0 0 0 3】

直交周波数分割多重化 (OFDM: Orthogonal Frequency Division Multiplexing) を使用 20  
するセルラー無線通信システムにおいては、信号のタイミングに対して同期をとることにより、信号から情報を抽出する信号受信機によって利用される高速フーリエ変換 (FFT: Fast Fourier Transform) ウィンドウの正確な位置決めを行なうことができる。

【0 0 0 4】

複数の基地局 (BTS) と複数の移動通信装置とを有する任意のセルラー無線通信システムにおいて、同期プロセスは、システムを操作できるように BTS と移動通信装置との間で頻繁に発生しなければならない。以下、移動通信装置を単に UE (ユーザ機器) と称する。

【0 0 0 5】

また、各 BTS は、一般にセルとして知られる地理的な送信領域を規定する。この送信領域内で特定の BTS にほぼ隣接する UE は、無線通信システムにアクセスする。セルラー無線通信システムにアクセスするための BTS を特定の UE が選択するプロセスは、セル選択として知られている。BTS 信号の受信を最適化するために、UE は、様々な BTS から受けた質が最も良い信号を特定するとともに、その受信機を切り換えて、最良の BTS に対して周波数を所定の時間合わせる必要がある。したがって、UE の移動性に起因して、1 つの BTS から UE 切換え位置としての他の BTS へのシームレスなハンドオフが可能となるように、同期プロセスが頻繁に使用されなければならない。

【0 0 0 6】

現在の殆どのセルラー無線通信システムにおいて、高速なシステムアクセスおよびセル選 40  
択は、適切な移動 UE 操作において必須の機能である。高速取得の目的は、所望の BTS に対して UE を同期させることができるようにすることである。隣り合う BTS 間で信号 (干渉を含む) パワーを同期化して測定するとともに、質が最も良い信号すなわち最大  $C/I$  (搬送波対干渉: carrier-to-interference) 比を用いて BTS を選択して切り換えるため、セル選択および再選択は、UE によって行なわれる。

【0 0 0 7】

OFDM (直交周波数分割多重化) を使用する無線通信システムにアクセスするための既存の解決策は、SISO (単入力-単出力: single input - single output) 構成下での高速パケットアクセスのため、無線 LAN (ローカル・エリア・ネットワーク) システム 50  
において設計されていた。しかしながら、無線 LAN は、シームレスな BTS ハンドオフ

を必要とするUEの移動性を扱う能力を有していない。一方、幾つかの携帯電話システム、例えば3G UMTSは、セル選択、BTS識別、BTS C/I比測定を行なうことができる。

#### 【0008】

マルチ入力マルチ出力-OFDM (MIMO-OFDM: Multiple Input Multiple Output OFDM) は、周波数および時間の両方において高速フェージングを伴う無線チャネルを通じて高速データを送信するために使用される、新規で高スペクトルな効率的技術である。高速ダウンリンクパケットデータ送信システムにおいて、物理層パケット構造の設計は、基本的な態様である。

#### 【0009】

OFDM技術は、DAB規格、DVB-T規格およびIEEE 802.11規格によって採用されてきた。DABおよびDVB-Tは、オーディオ・ビデオエリア・ブロードキャストティングにおいて使用される。これらのシステムにおいて、信号は、連続するデータストリームの状態で送信される。ここでは高速パケットアクセスが重要でないため、プリアンブルは必要とされない。また、DABおよびDVB-Tは、1つの周波数ネットワークに適用される。この場合、全ての送信機は、ブロードキャストティングとして、同じ信号を送信する。隣り合う送信機からの干渉は、適切な構造のプレフィックスによって扱うことができる有効エコーとして処理することができる。IEEE 802.11は、無線LAN規格である。それは、パケットベースのOFDM送信システムである。この規格では、プリアンブルヘッダが導入される。

#### 【0010】

各送信機および各受信機が複数のアンテナを有するMIMO-OFDM (マルチ入力マルチ出力-OFDM) システム内での同期化は、非常に困難である。作業の複雑さに加えて、セル全体で高い成功率を得ることができるようにより、高速同期プロセスは、非常に低いC/I比状態で非常に信頼できるものでなければならない。また、移動性が高いことにより高いドップラーが広がり、これにより確実な同期化が更に困難になる。

#### 【0011】

MIMO-OFDMシステムにおいては、2段階で同期化を行なうことができる。最初に、フレーム内における最初のOFDMシンボルの開始位置の場所のおおよその範囲を決定するために、フレーム同期 (粗同期とも呼ばれる) が行なわれる。次に、正確なFFTウィンドウの位置を決定して、周波数領域での復調を正確に行なえるようにするために、タイミング同期 (微同期とも呼ばれる) が行なわれる。

#### 【0012】

従来、微同期は、時間領域で行なわれる。これは、選択時間スロットで相互相関計算を受信機が行なえるように、予め知られたパイロットトレーニングシーケンスを時間領域内に挿入することにより行なわれる。

#### 【0013】

例えば、図1-1および図1-2に示されるように、IEEE 802.11規格のOFDMフレーム構造は、幾つかの繰り返される短いOFDMシンボル (参照符号5で全体的に示される) を使用する。これらのOFDMシンボルは、副搬送波選択のため、フレームの初めの時間領域内に幾つかのヘッダとして配置されている。そして、その後に、微同期のためのトレーニングOFDMシンボル207が続く。ヘッダ5は、フレーム同期 (すなわち、粗同期) のために使用される。トレーニングOFDMシンボル207は、FFTウィンドウを正確に位置決めして、周波数領域の復調を正確に行なえるようにするために使用される。トレーニングOFDMシンボル207の後には、TPS OFDM205と、データOFDMシンボル30とが続く。

#### 【発明の開示】

#### 【発明が解決しようとする課題】

#### 【0014】

周波数領域 (図1-2参照) で更に明確に示されるTPS (送信パラメータ信号) OFD

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Mシンボル205は、変調時間および適応コーディングに対応する周波数と共に送信される。トレーニングOFDMシンボル、TPS OFDMシンボルおよびデータOFDMシンボルは、全ての副搬送波を使用する。802.11システムにおいて、粗同期用繰り返しヘッダは、4番目の全ての副搬送波上でのみ送信される。このような構成は、1つの送信アンテナだけを有する単純なSISO OFDMシステムにおいてのみ適している。MIMO-OFDMシステムの場合には、複数の送信アンテナが存在するため、プリアンプル構成が更に複雑になる。また、移動体通信の場合には、マルチセル環境、BTS情報が利用できない最初のアクセスのための要件、BTS切換えおよびソフトハンドオフにより、効果的なプリアンプル構成が更に難しくなる。

#### 【0015】

セル取得および同期化のプロセスにおける既存の方法は、比較的長いアクセス時間を必要とするUMTS WCDMAシステムにより採用される3段階同期化手法を使用する。時間領域で微同期を行ない得る間、MIMOチャネルの自己干渉は、 $C/I$ が非常に低い状態で、この手法の性能を制限する。相関の長さを長くすると、時間領域での微同期の性能を高めることができるが、オーバーヘッドが増大し、処理が複雑になってしまう。既存の構成は、1つの送信アンテナと1つの受信アンテナとを有するシステムにおける時間領域トレーニングシーケンス相関に基づいている。しかしながら、そのような時間領域同期手法を単に拡張させただけでは、特に $C/I$ 比が低い用途において、性能が低下してしまう。性能低下の原因は、時間領域で減少することが容易ではないMIMOチャネル間の自己干渉である。

#### 【課題を解決するための手段】

#### 【0016】

本発明の1つの広範な態様は、ヘッダシンボルフォーマットを送信するようになっているMIMO-OFDM送信機であって、ヘッダOFDMシンボルの副搬送波が、複数のアンテナのそれぞれにおいて、副搬送波の非連続なセットに分割され、各アンテナが、副搬送波の各セット上でのみヘッダOFDMシンボルを送信するMIMO-OFDM送信機を提供する。

#### 【0017】

幾つかの実施形態においては、 $N$ 個のアンテナが存在し、 $N$ 個の副搬送波によって分離された副搬送波の異なるセットが複数のアンテナのそれぞれに対して割り当てられる。

#### 【0018】

幾つかの実施形態において、前記ヘッダシンボルは、複数のアンテナのそれぞれにおいて、専用パイロットチャネル副搬送波上に、多重化された専用パイロットチャネルを含むとともに、共通同期チャネル副搬送波上に、共通同期チャネルを含む。

#### 【0019】

幾つかの実施形態において、前記ヘッダOFDMシンボルは、複数のアンテナのそれぞれにおいて、多重化されたブロードキャスト副搬送波を更に含む。

#### 【0020】

幾つかの実施形態において、前記送信機は、更に、プレフィックスと、プレフィックスの後に続き且つ前記ヘッダOFDMシンボルフォーマットを有する2つの同一のOFDMシンボルとを有するプリアンプルを送信するようになっている。幾つかの実施形態において、前記プレフィックスは、前記2つの同一のOFDMシンボルの巡回拡張子である。

#### 【0021】

幾つかの実施形態において、前記パイロットチャネルは、効率的なBTS識別を行なうことができるBTS固有のマッピングされた複合シーケンスを有する。

#### 【0022】

幾つかの実施形態において、前記共通同期チャネルは、高速で且つ正確な初期取得を行なえるように設計されている。

#### 【0023】

幾つかの実施形態において、前記共通同期チャネルは、粗同期および微同期のために使用

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され、前記パイロットチャネルは、微同期のために使用される。

【0024】

幾つかの実施形態において、前記共通同期チャネルは、1つの送信機の送信アンテナ毎に異なるが通信ネットワーク内の様々な送信機の各送信アンテナに共通する複合シーケンスを送信するために使用される。

【0025】

幾つかの実施形態において、前記送信機は更に、前記プリアンプルから始まるOFDMフレームを送信するようになっており、当該OFDMフレームは、該OFDMフレーム内の残りのOFDMシンボルにわたって分散パイロットを有する。

【0026】

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幾つかの実施形態において、前記プリアンプル中、N個の送信アンテナのそれぞれにおいて、専用パイロットチャネル副搬送波が送信され、共通同期チャネル副搬送波が送信され、そしてブロードキャストチャネル副搬送波が送信される。

【0027】

幾つかの実施形態において、前記プリアンプルのOFDMシンボルの副搬送波は、所定の順序で配置される {N個の送信アンテナのそれぞれにおける専用パイロットチャネル、N個の送信アンテナのそれぞれにおける共通同期チャネル副搬送波} から成る繰り返しシーケンスとして編成される。

【0028】

幾つかの実施形態において、前記プリアンプルのOFDMシンボルの副搬送波は、所定の順序で配置される {N個の送信アンテナのそれぞれにおける少なくとも1つの専用パイロットチャネル副搬送波、N個の送信アンテナのそれぞれにおける少なくとも1つの共通同期チャネル副搬送波、少なくとも1つのブロードキャストチャネル副搬送波} から成る繰り返しシーケンスとして編成される。 20

【0029】

本発明の別の広範な態様は、ヘッダシンボルフォーマットを受信するようになっているMIMO-OFDM受信機であって、ヘッダOFDMシンボルの副搬送波は、複数のアンテナのそれぞれにおいて、副搬送波の非連続なセットに分割され、各アンテナは、副搬送波の各セット上でのみヘッダOFDMシンボルを送信するMIMO-OFDM受信機を提供する。 30

【0030】

幾つかの実施形態において、前記受信機は、N個の送信アンテナから、N個の副搬送波によって分離された副搬送波の異なるセットで受信するようになっており、該副搬送波の異なるセットは複数の送信アンテナのそれぞれに対して割り当てられる。

【0031】

幾つかの実施形態において、前記受信機は、共通同期チャネル副搬送波及び／又は専用パイロットチャネル副搬送波に基づいて微同期を更に行なうようになっている。

【0032】

本発明の別の広範な態様は、パケットデータフレーム構造を送信するようになっている送信機を提供する。該パケットデータフレーム構造は、ネットワークの同期期間に対応する長さを有するスーパーフレームを備え、該スーパーフレームは、複数の無線フレームを含み、各無線フレームは、適応コーディングおよび変調期間に対応する複数のTPS（送信パラメータ信号）フレームを含み、各TPSフレームは、エアーインタフェーススロットサイズに対応する複数のスロットを含み、各スロットは複数のOFDMシンボルを含み、各OFDMフレームの最初のTPSフレームの最初のスロットの最初の2つのシンボルは、ヘッダOFDMシンボルとして使用される。 40

【0033】

幾つかの実施形態において、前記ヘッダOFDMシンボルは、該ヘッダOFDMシンボルの副搬送波が複数のアンテナのそれぞれにおいて副搬送波の非連続なセットに分割されるヘッダOFDMシンボルフォーマットを有し、各アンテナは、副搬送波の各セット上での 50

みヘッダOFDMシンボルを送信する。

【0034】

幾つかの実施形態において、前記ヘッダOFDMシンボルは、複数のアンテナのそれぞれにおいて、多重化された専用パイロットチャネル副搬送波を含むとともに、共通同期チャネル副搬送波を含む。

【0035】

幾つかの実施形態において、前記ヘッダOFDMシンボルは、複数のアンテナのそれぞれにおいて、多重化されたブロードキャストチャネル副搬送波を更に含む。

【0036】

幾つかの実施形態において、前記送信機は、スロット持続時間が変わることなく且つスロットよりも上のフレーム構造を変えないことなく1スロット毎に異なる数のOFDMシンボルを送信することにより、複数の異なるモードで送信するようになっている。

【0037】

幾つかの実施形態において、1スロット当たりのOFDMシンボルの数が増大するモードは、サンプリング周波数を変えないことなくOFDMシンボル持続時間およびFFTサイズを短くすることにより実現される。

【0038】

幾つかの実施形態において、前記送信機は、更に、TPSフレーム毎にユーザの各組に対して送信するとともに、どのユーザがTPSフレーム全体を復調するべきかをTPSフレームごとの信号に送信するようになっている。

【0039】

本発明の別の広範な態様は、OFDM受信機で同期を行なう方法を提供する。この方法は、少なくとも1つの受信アンテナのそれぞれにおいて、受信信号をサンプリングして時間領域サンプルの各セットを形成し、少なくとも1つの粗同期位置を決定し、少なくとも1つの受信アンテナのそれぞれにおいて、

a) 前記少なくとも1つの粗同期位置のうちの1つに関する複数の候補微同期位置のそれぞれにおいて、

i) 受信アンテナ毎に、候補微同期位置に対してFFTウィンドウを位置決めするとともに、FFTにより、時間領域サンプルを周波数領域成分の各セットに変換し、

ii) 前記少なくとも1つの送信アンテナ毎に、周波数領域成分のセットから送信アンテナに対応する受信された各トレーニングシーケンスを抽出し、

iii) 送信アンテナ毎に、受信された各トレーニングシーケンスと周知の各送信トレーニングシーケンスとの間の相関を計算し、

iv) 少なくとも1つの送信アンテナにおいて相関を組み合わせて、候補同期位置毎に全体の相関結果を形成し、

b) 複数の相関値から微同期位置を決定し、

少なくとも1つの受信アンテナからの複数の微同期位置を組み合わせて全体の微同期位置とする、

ことを含む。

【0040】

幾つかの実施形態において、粗同期位置は、受信アンテナ毎に決定されるとともに、各微同期位置を決定するために使用される。

【0041】

幾つかの実施形態において、粗同期位置が受信アンテナ毎に決定され、これらの位置のうちで最も早い位置が使用されて、全ての受信アンテナにおける微同期位置が決定される。

【0042】

幾つかの実施形態において、前記粗同期位置は、2つのOFDMシンボル持続時間にわたって時間領域サンプル間の相関ピークを探すことにより、少なくとも1つの受信アンテナにおいて時間領域で決定される。

【0043】

幾つかの実施形態において、前記方法は、少なくとも2つのアンテナを有するOFDM受信機で適用され、少なくとも1つの受信アンテナからの複数の微同期位置を組み合わせて全体の微同期位置とすることは、微同期位置のうちの最も早い位置を選択することを含む。

#### 【0044】

幾つかの実施形態において、受信信号をサンプリングして時間領域サンプルのセットを形成することは、少なくとも3つのOFDMシンボル持続時間において行なわれ、少なくとも1つの粗同期位置を決定することは、2つのOFDMシンボル持続時間にわたって受けた時間領域サンプル間の相関ピークを探すことにより時間領域で粗同期を行なって、

a) 1つのOFDMシンボル持続時間を有する第1の期間中に受けた時間領域サンプルの第1のセットと、前記第1の期間の直ぐ次の第2の期間であってOFDMシンボル持続時間を有する第2の期間中に受けた時間領域サンプルの第2のセットとの間で計算された相関である複数の相関値のそれぞれを、前記第1の期間における複数の開始時間のそれぞれにおいて計算し、

b) 前記複数の相関値で最大となる粗同期位置を特定する、  
ことにより、粗同期位置を特定することを含む。

#### 【0045】

幾つかの実施形態において、少なくとも1つの送信アンテナにおいて相関を組み合わせて候補同期位置毎に全体の相関結果を形成することは、候補同期位置毎に少なくとも1つの送信アンテナにおける相関を一緒に乗算することを含む。

#### 【0046】

幾つかの実施形態において、前記方法は、送信アンテナが1つで且つ受信アンテナが1つのシステムに対して適用される。

#### 【0047】

幾つかの実施形態において、前記トレーニングシーケンスは、共通同期チャネル副搬送波上で受信される。

#### 【0048】

幾つかの実施形態において、前記トレーニングシーケンスは、OFDMフレームプリアンブル中に受信される。

#### 【0049】

幾つかの実施形態において、前記トレーニングシーケンスは、専用パイロットチャネル副搬送波上で受信される。

#### 【0050】

幾つかの実施形態において、トレーニングシーケンスは、OFDMフレームプリアンブル中に受信される。

#### 【0051】

本発明の別の広範な態様は、少なくとも1つの受信アンテナと；前記少なくとも1つの受信アンテナ毎に設けられ、受信信号をサンプリングして、時間領域サンプルの各セットを形成するようになっている受信回路と、少なくとも1つの粗同期位置を決定するようになっている粗同期装置と、微同期装置と、を備え、該微同期装置は、少なくとも1つのFFTと、少なくとも1つの相関器と、少なくとも1つのコンバイナとを備え、とともに、少なくとも1つの受信アンテナのそれぞれで、

a) 前記少なくとも1つの粗同期位置のうちの1つに関する複数の候補微同期位置それぞれにおいて、

i) 受信アンテナ毎に、候補微同期位置に対してFFTウィンドウを位置決めするとともに、FFTにより、時間領域サンプルを周波数領域成分の各セットに変換し、

ii) 前記少なくとも1つの送信アンテナ毎に、周波数領域成分のセットから送信アンテナに対応する受信された各トレーニングシーケンスを抽出し、

iii) 送信アンテナ毎に、受信された各トレーニングシーケンスと周知の各送信トレーニングシーケンスとの間の相関を計算し、

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i v) 少なくとも1つの送信アンテナにおいて相関を組み合わせ、候補同期位置毎に全体の相関結果を形成し、  
b) 複数の相関値から微同期位置を決定する、  
ようになっており、  
少なくとも1つの受信アンテナからの複数の微同期位置を組み合わせ、全体の微同期位置とするようになっているOFDM受信機を提供する。

【0052】

幾つかの実施形態において、前記受信機は、少なくとも2つの受信アンテナを有し、微同期位置のうちの最も早い位置を選択することにより、少なくとも1つの受信アンテナからの複数の微同期位置を組み合わせ、全体の微同期位置とする。

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【0053】

幾つかの実施形態において、前記受信機は、候補同期位置毎に少なくとも1つの送信アンテナにおける相関と一緒に乗算することにより、少なくとも1つの送信アンテナにおいて相関を組み合わせ、候補同期位置毎に全体の相関結果を形成するようになっている。

【0054】

幾つかの実施形態において、前記受信機は、共通同期チャネル副搬送波上でトレーニングシーケンスを受信するようになっている。

【0055】

幾つかの実施形態において、受信機は、専用パイロットチャネル副搬送波上でトレーニングシーケンスを受信するようになっている。

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【0056】

本発明の別の広範な態様は、微同期を行なう方法を提供する。この方法は、少なくとも1つの各受信アンテナで、少なくとも1つの送信アンテナ毎に受けた各周波数領域トレーニングシーケンスを含むOFDMシンボルを受信し、周知の周波数領域トレーニングシーケンスと、受信した周波数領域トレーニングシーケンスとの間で最大相関を見つけることにより、周波数領域で微同期を行なうことを含む。

【0057】

本発明の別の広範な態様は、微同期を可能にする信号を送信する方法を提供する。この方法は、少なくとも1つの各送信アンテナから、各周波数領域トレーニングシーケンスを含むOFDMシンボルを送信することを含む。

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【0058】

幾つかの実施形態において、異なる周波数領域トレーニングシーケンスは各送信アンテナによって送信されるが、同じ周波数領域トレーニングシーケンスは、他の送信機の対応するアンテナによって送信される。

【0059】

本発明の別の広範な態様は、OFDM受信機でセル選択を行なう方法を提供する。この方法は、少なくとも1つの各送信アンテナで、受信信号をサンプリングして、時間領域サンプルの各セットを形成し、少なくとも1つの粗同期位置を決定し、少なくとも1つの受信アンテナのそれぞれで、

a) 受信信号内の共通同期チャネル副搬送波から抽出された少なくとも1つの受信した共通同期シーケンスと、複数の送信アンテナのそれぞれの対応する共通同期シーケンスとの間で周波数領域相関を行なうことにより、複数の候補相関ピークを特定し、

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b) 更なる処理のために、M個の最も強い相関ピークを選択し、

c) 各相関ピークで、時間領域サンプルを複数の周波数領域成分に再変換するとともに、送信機固有の情報を含むパイロットチャネル副搬送波を処理して、各相関ピークに関連付けられた送信機を特定し、

d) そのように特定された各送信機においてC/Iまたは同様の値を決定し、任意の少なくとも1つの受信アンテナにおいて決定されたC/Iが最も大きい送信機を選択する、  
ことを含む。

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**【0060】**

幾つかの実施形態において、受信信号内の共通同期チャネル副搬送波から抽出された少なくとも1つの受信した共通同期シーケンスと、複数の各送信アンテナの対応する共通同期シーケンスとの間で周波数領域相関を行なうことにより、複数の候補相関ピークを特定することは、

a) 前記少なくとも1つの粗同期位置のうちの1つに関する複数の各候補微同期位置のそれぞれにおいて、

i) 受信アンテナ毎に、候補微同期位置に対してFFTウィンドウを位置決めするとともに、FFTにより、時間領域サンプルを周波数領域成分の各セットに変換し、

ii) 少なくとも1つの各送信機の送信アンテナによって送信された少なくとも1つの共通同期シーケンス毎に、周波数領域成分のセットから前記送信アンテナに対応する受信された各トレーニングシーケンスを抽出し、

iii) 少なくとも1つの共通同期シーケンス毎に、受信された各共通同期シーケンスと周知の各共通同期シーケンスとの間の相関を計算し、

iv) 相関を組み合わせて、候補同期位置毎に全体の相関結果を形成し、

b) 相関の極大値である少なくとも1つのピークを前記相関において決定する、ことを含む。

**【0061】**

幾つかの実施形態において、前記方法は、選択された送信機の微同期位置に基づいて、時間領域サンプルを周波数領域成分に再変換するとともに、その送信機における専用のパイロットチャネルに基づいて更なる微同期を行なうことを更に含む。

**【0062】**

幾つかの実施形態において、前記方法は、ヘッダシンボルフォーマットを有するMIMO-OFDMフレームフォーマットに適用され、ヘッダシンボルの副搬送波が複数のアンテナのそれぞれにおいて非連続の副搬送波のセットに分割され、各アンテナは、対応する副搬送波のセット上でのみヘッダシンボルを送信し、該ヘッダシンボルは、多重化されたパイロットチャネル副搬送波と、複数のアンテナのそれぞれに共通の同期チャネル副搬送波とを含み、フレームは、2つの同一のヘッダOFDMシンボルから始まり、そのヘッダOFDMシンボル中において、パイロットチャネル副搬送波のコンテンツが繰り返されるとともに、同期チャネル副搬送波のコンテンツが繰り返され、共通同期チャネル副搬送波は、1つの基地局の各アンテナで異なるが複数の基地局にわたって共通の複合シーケンスを搬送し、専用パイロットチャネル副搬送波のコンテンツは、少なくとも局所的に特定の基地局に固有のものである。

**【0063】**

幾つかの実施形態において、前記方法は、送信機の切換えのため、そのように特定された送信機毎に、C/Iまたは同様の値を所定の時間にわたって平均化し、その時間の最後に、現在選択されて送信されたものと異なる場合には、最も大きい平均C/Iまたは同様の値を用いて前記送信機の送信機スイッチを起動させることを更に含む。

【発明を実施するための最良の形態】

**【0064】**

以下、添付図面を参照しつつ、本発明の好ましい実施形態を詳細に説明する。

**【0065】**

図2-1を参照すると、本発明の一実施形態によって与えられるOFDMパケットフレーム構造が示されている。送信OFDMシンボルストリームがそのようなフレームに編成されている。各フレームは、3つの主要な構成要素、すなわち、プリアンプル300と、分散パイロット302と、トラフィックデータシンボル304とから成る。プリアンプルの挿入により、UE（ユーザ機器）は、以下の基本的な動作、すなわち、高速BTS（基地局）アクセス、BTS識別およびC/I比測定、フレーミング・タイミング同期、周波数・サンプリングクロックオフセット評価、初期チャネル評価を行なうことができる。スペクトル効率および無線能力を最大にするためには、オーバーヘッドが最小限のフレームプリ

アンブルを設計することが重要である。

【0066】

図2-2を参照すると、MIMO-OFDMのためのフレーム階層が本発明の一実施形態にしたがって以下のように編成されている。すなわち、OFDMスーパーフレーム500（2つ示されている）が最も高いレベルにある。スーパーフレームの持続時間は、ネットワーク同期時間（例えば1秒）によって決定される。スーパーフレームは、OFDMフレームとも称される幾つかの10ms無線フレーム502から成る。1つの1sスーパーフレーム500の中には、100個の10ms OFDMフレーム502がある。

【0067】

適応コーディング変調（ACM: Adaptive Coding Modulation）をサポートするため、高速信号チャネル（TPSチャネル送信パラメータ信号）が導入される。各OFDMフレーム502は、複数のTPSフレーム504に分割される。図示の例では、10ms無線フレーム502毎に5つの2ms TPSフレームがある。幾つかの実施形態においてTPSのために使用されるフレーム長は、ACM単位の持続時間と同じである。また、各TPSフレームは、現在のTPSフレームが自分のためのデータを含むか否かを各ユーザが判断できる信号情報を含む。1つのTPSフレームは複数のユーザのためのデータを含んでも良い。

【0068】

TPSフレーム504は、更に幾つかのスロット506に分割されても良い。各スロットは、幾つかのOFDMシンボルから成る。図示の例において、各TPSフレーム504は、3つのスロット506に分割されている。スロット506の持続時間は、エアインタフェーススロットサイズによって決まる。最も小さい送信単位は、1つのOFDMシンボル508, 510である。1つのOFDMシンボルの持続時間は、送信環境特性、例えば、最大チャネル遅れ、システムサンプリングクロックおよび最大ドップラーによって決定される。図示の例においては、1つのスロット506毎に4つのOFDMシンボル508, 510がある。

【0069】

OFDMシンボル間にガードインターバルを挿入することによって生じるオーバーヘッドを減らすため、異なるシンボル持続時間と異なるプレフィックスとをそれぞれが有する異なるOFDMシンボルモード、例えば0.5kモードおよび1kモードを設計することができる。システムを簡単にするため、モード切り換えの際、サンプリング周波数は変更されことなく維持される。以下、これらの異なるモードについて詳細に説明する。

【0070】

図2-2のフレーム構造は、UMTSエアインタフェースに適合するフレーム構造階層の一例を示している。OFDMシンボルレベルでは、2つの異なるタイプのOFDMシンボルが存在する。これらのOFDMシンボルは、プリアンブルOFDMシンボル508と、レギュラーデータシンボル510とを含む。

【0071】

時間領域を示している図4を参照すると、各OFDMフレームは、プレフィックス607によって先行される幾つかの同じヘッダOFDMシンボル603, 605から成るプリアンブルで始まる。プレフィックス607は、ヘッダOFDMシンボルの巡回拡張子である。同期を支援するために、繰り返し構造が使用される。2つの同一のシンボルが識別されるまで、隣り合うOFDMシンボル間で相関を行なうことにより、OFDMフレームの開始点を見つけることができる。一例として、1つのOFDMシンボル毎に1056個のサンプルを使用しても良い。プリアンブルにおいては、プレフィックス607中に、ヘッダOFDMシンボルの最後の64個のサンプルが送信される。2番目のヘッダOFDMシンボルにおいてはプレフィックスが無い。ヘッダは定期的に挿入され、図2-2の例の場合、10ms毎に、すなわち、全てのOFDMフレームの開始時に、ヘッダの定期的な挿入が行なわれる。

【0072】

再び図2-2を参照すると、非ヘッダOFDMシンボルの場合、すなわち、レギュラーOFDMシンボル510の場合、全てのOFDMシンボルがプレフィックスを有することが好ましい。“1K”モードにおいては、32個のプレフィックスサンプルと、FFTサイズを示す1024個の実際のサンプルとがあり、シンボル毎に全部で1056個のサンプルがある。1/2Kモードにおいては、16個のサンプルプレフィックスと、シンボル毎に512個のサンプル（FFTサイズを示す）があり、全部で528サンプル/シンボルとなる。図2-2のフレーム構造を使用することにより、サンプリング周波数を変えることなく、これらの異なるモードを有利にサポートすることができる。1/2Kモードの場合、スロット506毎に2倍の数のOFDMシンボル510がある。ある瞬間に選択された特定のモードは、プレフィックスサイズが最大チャネル遅れよりも大きくなっていないなければならない。1/Kモードにおいては、僅かな副搬送波を用いて、より多くのOFDMシンボルが送られる。これは、高いドップラーまでかなり強力である。それは、シンボル持続時間が短いからである。また、副搬送波の間の間隔は大きく、ドップラーまでの許容度を高める。したがって、様々なFFTサイズに対応するが1つの受信機で同じサンプリングレートを持つ1つの一体的なフレーム構造がある。異なるモードであっても、同じプリアンブルが使用されることが好ましい。

#### 【0073】

OFDMはパラレル送信技術である。全体の有用な帯域幅が多くの副搬送波に分割され、各副搬送波が個別に変調される。本発明の一実施形態においては、複数のアンテナ送信を用いて異なるアンテナを分離するために、ヘッダ中において、全ての副搬送波が全ての送信アンテナで使用されるとは限らない。むしろ、副搬送波がアンテナ間で分割される。その一例について図3を参照しながら説明する。OFDMシンボル内に含まれる副搬送波の周波数はそれぞれ円によって表わされている。この例においては、MIMOシステム内に2つの送信アンテナがあると仮定する。図3は、周波数軸440に沿って離間する様々な副搬送波を有するOFDMシンボルを示している。時間軸402に沿って示されるように、ある瞬間の全ての副搬送波のコンテンツは、経時的に1つのシンボルを表わしている。この場合、最初の2つのOFDMシンボル408, 410は、専用のパイロットチャネル情報のために使用される。一方、残りのシンボル（2つだけが示されている、412, 414）は、レギュラーOFDMシンボルのために使用される。最初の2つのOFDMシンボル408, 410で送信される専用のパイロットチャネル情報は、第1アンテナによって送信される副搬送波と、第2アンテナによって送信される副搬送波とが交互になっている。これは、第1送信機の専用のパイロットチャネル情報を送信している第1の副搬送波404と、第2副搬送波の専用のパイロットチャネル情報を送信している副搬送波406とに関して示されており、このパターンは、その後、残りの副搬送波において繰り返す。他のOFDMシンボル412, 414は、両方のアンテナによって送信される情報を含む。他の間隔を代わりに使用できることは言うまでもない。また、その後、更に2つの送信アンテナがある場合には、パイロットチャネル情報は、全ての送信アンテナ間で、幾つかの所定のパターンの副搬送波が交互に並ぶ。

#### 【0074】

他の実施形態においては、共通同期チャネルと専用パイロットチャネルとがヘッダシンボル上で周波数多重化される。専用パイロットチャネルおよび共通同期チャネルをそれぞれ送信するために、重複していない副搬送波の各セットが各アンテナに割り当てられる。

#### 【0075】

他の実施形態においては、共通同期チャネルと、専用パイロットチャネルと、ブロードキャストチャネルとがヘッダシンボル上で周波数多重化される。このような配置構成の下、ヘッダシンボルの全ての有用な副搬送波は、3つのグループに分離される。これらの3つのグループは、共通同期チャネルと、専用パイロットチャネルと、ブロードキャストチャネルとにそれぞれマッピングされる。

#### 【0076】

2-送信機ダイバーシティを用いてMIMOシステムにおいて異なるチャネルをマッピン

グした一例が図5に示されている。この例においては、4つのOFDMシンボル712, 714, 716, 718が示されており、そのうちの2つのOFDMシンボル712, 714がヘッダシンボルである。ヘッダシンボル712, 714中においては、全ての2番目の副搬送波が第1のアンテナのために使用され、残りの副搬送波が第2アンテナのために使用される。これは、多数のアンテナに対して簡単に一般化される。この例においては、MIMOシステム内に2つの送信アンテナがあると仮定する。1番目の副搬送波700から始まる各6番目の副搬送波は、第1送信機の専用パイロットチャネルの副搬送波のためのものである。2番目の副搬送波702から始まる各6番目の副搬送波は、第2送信機の専用パイロットチャネルの副搬送波のためのものである。3番目の副搬送波704から始まる各6番目の副搬送波は、第1送信機の共通同期チャネルの副搬送波のためのものである。4番目の副搬送波706から始まる各6番目の副搬送波は、第2送信機の共通同期チャネルの副搬送波のためのものである。5番目の副搬送波から始まる各6番目の副搬送波は、第1アンテナのためのブロードキャストチャネルの副搬送波のためのものであり、6番目の副搬送波710から始まる各6番目の副搬送波は、第2アンテナのためのブロードキャストチャネルの副搬送波のためのものである。

#### 【0077】

共通同期チャネルは、最初のアクセスにおいて普遍的なチャネルである。また、共通同期チャネルは、同期・予備チャネル評価のためにも使用できる。送信機ダイバーシティが適用される場合には、異なる送信機が共通同期副搬送波を共有する。前述したような場合には、共通同期チャネルが異なる送信機間で分割される。共通同期チャネルのために確保された副搬送波を変調するために、全ての端末によって知られる共通の複合シーケンスが使用される。システム内の全ての基地局により、同じ共通の同期シーケンスが送信される。複数の送信アンテナがあつて、各送信アンテナが固有の同期シーケンスを送信できる場合には、そのような1または複数の同期シーケンスがあつても良い。同期シーケンスを使用すると、移動局は、受信した同期シーケンスと送信された周知の同期シーケンスとの間で相関ピークを探すことにより、更なるBTS識別のための最初の同期位置を見つけることができる。

#### 【0078】

専用パイロットチャネルは、BTS／セル識別のために使用されるとともに、セル選択、セル切換えおよびハンドオフのためのC/I測定をサポートする。固有の複合シーケンス、例えばPNコードは、各BTSに対して割り当てられるとともに、専用パイロット副搬送波を変調するために使用される。複数の送信アンテナがある場合には、各アンテナによって、異なる固有のシーケンスが送信される。共通同期チャネルにおける場合とは異なり、様々な基地局が、異なるパイロットシーケンスを使用して送信する。異なるBTSに対して割り当てられたPNコードの準直交性により、アクセスポイント識別および初期干渉測定を行なうことができる。また、専用パイロットチャネルは、同期処理を支援するためにも使用できる。

#### 【0079】

ヘッダOFDMシンボルにおける副搬送波を完全に利用するためには、幾つかの副搬送波がブロードキャストチャネルとして使用されることが好ましい。図5の例においては、6つの全ての副搬送波のうちの2つがこの目的のために使用される。ブロードキャストチャネルは、重要なシステム情報を搬送することができる。STTD（時空送信ダイバーシティ）スキームは、同期アルゴリズムによって必要とされるヘッダOFDMシンボルの繰り返し構造を破壊するため、ブロードキャストチャネル（または、ヘッダOFDMシンボルにおける任意の副搬送波）のために使用することができない。しかしながら、全ての送信機によって同一の副搬送波でブロードキャスト情報を送信すると、送信機間で破壊的な干渉が生じる虞がある。この問題を解決するために、異なる送信機間でブロードキャストチャネルが分割される。したがって、送信アンテナが2つある場合には、送信アンテナがダイバーシティを提供できるように、副搬送波（ブロードキャストチャネルのためにマッピングされた）を送信アンテナのために二者択一的に割り当てることができる。プロ

ードキャストチャネルを更に向上させるためにパワーが増大されても良い。

#### 【0080】

異なるBTSからのブロードキャストイング情報が異なっても良い。幾つかの実施形態においては、ブロードキャスト情報が保護されるため、セルの境界に近いユーザは、強い干渉の存在下で、ブロードキャスト情報を正確に受信することができる。短いPNコードを使用して、ブロードキャスト情報を広めることができる。異なるコードを使用するために、隣り合うBTSが割り当てられる。ブロードキャストチャネルを挿入すると、プリアンブルオーバーヘッドが減少し、スペクトル効率が高まる。

#### 【0081】

特定の基地局に固有の情報を送信するために、ブロードキャストチャネルが使用される。10  
2つのアンテナのための組み合わせられたブロードキャストチャネル搬送波で1つのブロードキャストメッセージが送られても良い。パイロットチャネルと同期チャネルとブロードキャストチャネルとから成るようにプリアンブルヘッダシンボルを設計することにより、プリアンブルヘッダのオーバーヘッドが減少する。高速で且つ正確な初期取得を成すことができるように、共通同期チャネルが設計される。BTS固有のマッピングされたサインを有する専用パイロットチャネルにより、BTS識別を効率的に行なうことができる。MIMOチャネル評価のために、共通同期チャネルとパイロットチャネルとが互いに組み合わせられて使用される。また、共通同期チャネルと専用パイロットチャネルとを組み合わせることで使用することにより、高精度な同期が可能になる。周波数領域トレーニングシンボルは、タイミングエラーおよびマルチパス環境に対して強い。プリアンブル構造により、自20  
由度のあるユーザ機器は、より効率的なアルゴリズムを実行することができる。

#### 【0082】

なお、一実施形態における専用パイロットチャネル間での副搬送波の特定の破壊、他の実施形態における専用パイロットチャネルと共通同期チャネルとの間での副搬送波の特定の破壊、他の実施形態における専用パイロットチャネルと共通同期チャネルとブロードキャストチャネルとの間での副搬送波の特定の破壊は、単なる特定の例である。これらは、任意の適当な方法で割り当てることができる。

#### 【0083】

図6を参照すると、MIMO-OFDM送信機10の概念的な概略図が示されている。4  
つのOFDMシンボル201から成る第1のサンプルセットが第1送信アンテナ21から30  
送信されて示されており、また、4つのOFDMシンボル203から成る第2のサンプルセットが第2送信アンテナ23から送信されて示されている。一般に、OFDM送信機は、 $N_{ant}$ 送信アンテナを有する。この場合、 $N_{ant}$ は、設計パラメータである。MIMO-OFDM送信機10内において、デマルチプレクサ23から発せられるデータは、送信アンテナ21に接続された第1のOFDM部24または送信アンテナ23に接続された第2のOFDM部26のいずれか一方に送られる。これらOFDM部は、OFDMフレームおよびOFDMシンボルの副搬送波上にデータを編成する。各副搬送波は、異なる直交する周波数にある。各OFDM部24、26はそれぞれ、ヘッダOFDMシンボルを挿入するヘッダインサータ29を有する。OFDMシンボル201、203から成るサンプルセッ  
40  
トは、送信アンテナ21、23からそれぞれ送信されたOFDMフレームの最初の4つのOFDMシンボルを示している。この場合、データシンボルまたはパイロットシンボルから成る各列がOFDMシンボルである。1番目のOFDMシンボル13および2番目（1番目と同じ）のOFDMシンボル14は、第1送信アンテナ21によって送信されたOFDMフレームに固有の2つのヘッダOFDMシンボルを示している。同様に、3番目のOFDMシンボル17および4番目（3番目と同じ）のOFDMシンボルは、第2送信アンテナ23によって送信されたOFDMシンボルに固有の2つのヘッダOFDMシンボルを示している。4つのOFDMシンボル15、16、19、20は、一般に、複数のデータシンボルから成る異なるOFDMシンボルであり、この場合、少なくとも1つのデータシンボルが各OFDM副搬送波上に参照符号11で示されている。OFDMフレーム全体は、一般に、更に多くのデータシンボルを有する。また、OFDMシンボル201は、OF50

DMシンボル203と同じタイミングで、同時に送信される。

【0084】

この例において、2つの同一のヘッダOFDMシンボルは、専用パイロットチャネル副搬送波12と共通同期チャネル副搬送波9とから成る。また、図示しないブロードキャストチャネル副搬送波があっても良い。専用パイロットチャネル副搬送波は、C/I比測定、BTS識別、後述する微同期のために使用される。また、これらは、初期チャネル評価のために使用することもできる。共通同期チャネル副搬送波9は、粗同期および微同期、初期アクセス、初期チャネル評価のために使用される。

【0085】

図示の例において、2つのヘッダOFDMシンボル中、全部で4つの連続する副搬送波のうち1番目の副搬送波は、送信アンテナ21によって送信される専用パイロットチャネルシンボルを搬送するために使用される。同様に、全部で4つの連続する副搬送波のうち2番目の副搬送波は、送信アンテナ23によって送信される専用パイロットチャネルシンボルを搬送するために使用される。

【0086】

パイロットチャネル副搬送波12、25上で送信される専用パイロットチャネルシンボルは、基地局／セクタ固有のPNシーケンスによって規定される。基地局に固有の複合擬似ランダムPNシーケンスからの一連のシンボルは、ヘッダOFDMシンボル内における専用パイロットチャネル副搬送波の位置にマッピングされる。

【0087】

2つのヘッダシンボル内における全部で4つの連続する副搬送波のうち3番目の副搬送波は、送信アンテナ21によって送信された共通同期チャネルシンボルを搬送するために使用される。同様に、全部で4つの連続する副搬送波のうち4番目の副搬送波は、送信アンテナ23によって送信された共通同期チャネルシンボルを搬送するために使用される。

【0088】

共通同期副搬送波9、27上で送信される共通同期チャネルシンボルは、各送信アンテナ21、23において固有の複合擬似ランダムPNシーケンスによって規定される。この複合擬似ランダムPNシーケンスからの一連のシンボルは、ヘッダOFDMシンボル内における共通同期チャネル副搬送波上にマッピングされる。すなわち、各送信アンテナによって送信される各フレームの共通同期チャネルシンボルは、その送信アンテナに固有であるが他の基地局の対応する送信アンテナにとっても同一のPNコードを使用する。この例において、 $PN_{SYNC}^{(1)}$ は送信アンテナ21に関連付けられ、 $PN_{SYNC}^{(2)}$ は送信アンテナ23に関連付けられる。しかしながら、通信ネットワーク全体にわたる異なる送信機における同様のアンテナは、同じPNコードを使用する。例えば、ネットワーク内の全ての送信機の第1の送信アンテナ21における共通同期チャネルシンボルは、1つのPNコード( $PN_{SYNC}^{(1)}$ )を使用し、ネットワーク内の全ての送信機の第2の送信アンテナ22における共通同期チャネルシンボルは、異なる1つのPNコード( $PN_{SYNC}^{(2)}$ )を使用する。

【0089】

図7-1を参照すると、前述した各送信アンテナによって送信される2つの繰り返されたOFDMヘッダシンボルに基づいて粗同期を行なうようになっているMIMO-OFDM受信機機能のブロック図が示されている。OFDM受信機は、第1受信アンテナ734と第2受信アンテナ735とを有する(より一般的には、複数のN個の受信アンテナがあるが)。第1受信アンテナ734は、RF受信機736で第1の受信信号を受ける。第1の受信信号は、図6の2つの送信アンテナ21、23によって送信された2つの信号の組み合わせであるが、2つの各信号は、各送信アンテナと受信アンテナ734との間の各チャネルによって変更されてしまう。第2受信アンテナ735は、RF受信機739で第2の受信信号を受ける。第2の受信信号は、2つの送信アンテナ21、23によって送信された2つの信号の組み合わせであるが、2つの各信号は、各送信アンテナと受信アンテナ7

35との間の各チャネルによって変更されてしまう。4つのチャネル（2つの各送信アンテナと2つの各受信アンテナとの間にあるチャネル）は、時間および周波数に伴って変化するとともに、一般には、互いに異なっている。

#### 【0090】

1番目のヘッダシンボルの開始位置の場所のおおよその範囲を決定するため、受信信号の個々の時間サンプルに関し、第1受信アンテナ734のための粗同期が粗同期装置737により行なわれる。第2アンテナ735に関しても同様のプロセスが粗同期装置741により行なわれる。粗同期は、繰り返されたヘッダシンボルをOFDM送信機で使用的により簡略化される。粗同期装置737は、連続するOFDMシンボル内の時間領域信号サンプルに関して相関測定を行なう。最も高い相関測定をもたらす時間領域信号サンプルは、粗同期位置 $n_{coarse}$ である。その後、粗同期位置 $n_{coarse}$ が使用され、この粗同期位置 $n_{coarse}$ に基づいて、微同期で使用されるFFT機能内でFFTウィンドウの場所が見つけられる。

#### 【0091】

最初に、粗同期装置737は、時間領域粗同期処理を開始する。ランニングバッファ（図示せず）は、3つの連続するOFDMシンボル期間にわたって受信信号の個々の時間サンプルをバッファリングするために使用されるとともに、その後、2つの連続するOFDMシンボル持続時間中に集められたサンプル間の自己相関関係 $\gamma_t(n)$ を以下のように計算する。

#### 【0092】

##### 【数1】

$$\gamma_t(n) = \sum_{i=0}^{N_{header}-1} x(n+i)x^*(n+i+N_{header})$$

#### 【0093】

ここで $x(n)$ は、受信信号の時間領域サンプルであり、 $N_{header}$ は、1つのOFDMシンボル持続時間にわたって取得されたサンプル数である。

#### 【0094】

幾つかの実施形態においては、計算能力を蓄えるために、リアルタイム実施で、可動相関器が適用される。

#### 【0095】

一実施形態においては、相関値が閾値を上回るまで、 $n=1$ （ $n=N_{header}$ となるまで）に関して、 $\gamma_t(n)$ の値が次々に計算される。その後、最大値検索が可能になる。相関値の計算が続き、相関結果が再び閾値を下回るまで最大値検索処理が続く。最大相関値に対応するサンプル位置が粗同期位置である。すなわち、

#### 【0096】

##### 【数2】

$$n_{coarse} = \arg \max \{ |\gamma_t(n)| \}, \quad n \in \{ \gamma_t(n) > \gamma_{threshold} \}$$

#### 【0097】

閾値は、一般に、1フレーム内の平均自己相関値から計算される。あるいは、最大値を見つける他の方法は、例えば全長にわたって60個のシンボルがあるOFDMフレームにわたって各OFDMシンボルのための極大値を決定することである。その後、極大値の最大となる全体の最大値が取得される。このプロセスは、両方の粗同期で行なわれる。微同期を同時に進行させる場合、全体の粗同期位置は、2つの同期値の幾つかの組み合わせとして取得されても良く、また、そのように決定された2つの粗同期位置のうちの早い方となるべく取得されることが好ましい。もう1つの方法として、各微同期装置（後述する）は

、各粗同期位置から機能することができる。図7-2を参照すると、MIMO-OFDM微同期機能のブロック図が示されている。一実施形態において、微同期機能は、共通同期チャネル及び／又は専用パイロットチャネルを使用して前述したように各送信アンテナによって送信される2つの繰り返されたOFDMヘッダシンボルに基づいて微同期を行なうようになっている。更に一般的には、微同期機能は、幾つかの知られたトレーニングシーケンスが内部に組み込まれたOFDMフレームのために微同期を行なうことができる。また、微同期プロセスへの入力は、粗同期位置である。この粗同期位置は、前述した方法を使用して、あるいは、任意の他の適当な方法を使用して決定されても良い。図7-1の構成要素と同じ構成要素は、同様の参照符号が付されるとともに、実際の実施においては、図7-1と共通の同期装置が使用される場合に共有される。図7-2の機能は、1または複数の受信アンテナ毎に再現される。

#### 【0098】

微同期プロセスは、1または複数の受信アンテナ毎に行なわれ、その後、微同期位置の組み合わせに基づいて、全体の同期位置が取得される。概略的には、粗同期装置が粗同期位置( $S$ )  $n_{coarse}$ を決定すると、各微同期装置は、粗同期位置の両側で信号サンプルに関してFFTを行ない、OFDM副搬送波の周波数帯域にわたって周波数領域成分を形成する。各微同期装置は、周波数領域成分を検索して、FFTウィンドウの正確な場所を見つける。FFTウィンドウの正確な位置は、周波数領域内でOFDM復調を行なうために必要とされる。微同期装置は、粗同期位置 $n_{coarse}$ に対して規定される検索ウィンドウ内の周波数成分と周知のPNコード( $PN_{sync}^{(1)}$ および $PN_{sync}^{(2)}$ )との間で相関測定を行なうことにより、FFTウィンドウの正確な場所を見つける。各微同期装置によって行なわれる相関測定は、周波数領域内で行なわれ、また、周知の各PNコード( $PN_{sync}^{(1)}$ および $PN_{sync}^{(2)}$ )毎に、すなわち、送信アンテナ21, 23毎に(あるいは、存在する1または複数の送信アンテナに関して)、一組の相関測定が行なわれる。

#### 【0099】

各微同期装置は、検索ウィンドウ内で最初の信号サンプルから始まる $N_{symbol}$ 個の信号サンプルを選択する。ここで、 $N_{symbol}$ は、OFDMシンボル内の信号サンプルの数である。送信アンテナ毎に、各微同期装置は、周波数領域信号サンプルと送信アンテナに対応するPNコードとの間で相関測定を決定する。

#### 【0100】

更に具体的には、微同期検索は、 $n_{coarse}$ の近傍で行なわれる。検索ウィンドウが $2N+1$ である場合、検索範囲は( $n_{coarse}-N$ )から( $n_{coarse}+N$ )までである。仮に、 $n_{coarse}(i) = n_{coarse} + N - i$ が微検索ウィンドウ内のサンプルインデックスを表わすとする。ここで、 $i = 0, \dots, 2N$ である。微同期は、 $i = 0$ から始まる。その後、 $n_{start}(0)$ から始まる $N_{symbol}$ 個のサンプルが取得されて、プレフィックスが除去され、FFTが行なわれる。周波数領域内で受信されたOFDMシンボルは、以下のように書くことができる。

#### 【0101】

##### 【数3】

$$R(l, i) = FFT(x(n(i), l)), \quad n(i) = [n_{start}(i) + N_{prefix}, n_{start}(i) + N_{symbol} - 1]; \quad l = 1, \dots, N_{FFT}$$

#### 【0102】

ここで、 $N_{prefix}$ は、プレフィックスサンプルの数であり、 $N_{FFT}$ は、FFTサイズである。

#### 【0103】

異なる送信機の共通同期チャネルによって搬送される複合データ $R^{(j,k)}_{sync}$ が $R$ から抽出される。これは、MIMO-OFDMシステム内の異なる送信機間で共通同期チャネルが分割されるからである。更に一般的には、送信されたトレーニングシーケンスに対応する複合データが抽出される。 $R^{(j,k)}_{sync}$ と $PN^{(j)}_{sync}$ との間の相関は、以下の通りで



ある。

【0104】

【数4】

$$\gamma_j^{(j,k)}(i) = \sum_{m=0}^{N_{\text{sync}}-1} R^{(j,k)}_{\text{sync}}(m,i) PN^{*(j)}_{\text{sync}}(m), \quad i=0,\dots,2N$$

【0105】

ここで、 $j=1, 2, \dots, N_{\text{Tx}}$ は送信機を示しており、 $k=1, 2, \dots, N_{\text{Rx}}$ は受信機を示しており、 $PN^{(j)}_{\text{sync}}$ はj番目の送信機のための共通SYNC PNコードであり、 $N_{\text{sync}}$ は共通PNコードのサイズである。 10

【0106】

その後、開始点インデックス $n_{\text{start}}$ が一つの( $n_{\text{start}}(1) = n_{\text{start}}(0) - 1$ )だけシフトされ、他の $N_{\text{symbol}}$ サンプルが前述したように処理される。新たな周波数領域データ $R^{(j,k)}_{\text{sync}}(m, i)$ を得るため、我々は、FFTを再び行なう必要がある。この目的のため、反復法を使用して、計算の複雑性を減らすことができる。すなわち、

【0107】

【数5】

$$R(l,i) = R(l,i-1)e^{i2\pi(k-1)/N_{\text{FFT}}} + x(n_{\text{start}}(i) + N_{\text{prefix}}) - x(n_{\text{start}}(i-1) + N_{\text{symbol}} - 1) \quad 20$$

【0108】

ここで、 $N_{\text{FFT}}$ はFFTサイズである。 $R^{(j,k)}_{\text{sync}}(m, i)$ を抽出して、新たな相関関係が計算される。前述した手順は、 $n_{\text{start}}$ が微検索ウィンドウから出るまで続けられる。

【0109】

【数6】

$$n_{\text{fine}} = \arg \max \left( \prod_{j=1}^{N_{\text{Tx}}} \prod_{k=1}^{N_{\text{Rx}}} |\gamma_j^{(j,k)}(i)| \right) \quad 30$$

【0110】

各受信アンテナ毎に、異なるアンテナからの相関結果の積の最大値に対応する $n_{\text{start}}(i)$ を $i=0, \dots, 2N$ にわたって見つけることにより、15の各微同期位置を見つけることができる。数学的に説明すると、k番目の受信アンテナにおいては、以下にしたがって各微同期位置を選択することができる。

【0111】

【数7】

$$n_{\text{fine}}(k) = \arg \max \left( \prod_{j=1}^{N_{\text{Tx}}} |\gamma_j^{(j,k)}(i)| \right) \quad 40$$

【0112】

誤りの警報の可能性を減らすために、基準が設定されても良い。例えば、以下の条件が満たされている場合には、微同期が達成されていると見なして良い。

【0113】

【数8】

$$\max(\prod_{j=1}^{N_R} |\gamma^{(j,i)}(i)|) > N_{\text{threshold}} - \frac{1}{2N+1} \cdot \sum_{i=0}^{2N} \prod_{j=1}^{N_T} |\gamma^{(j,i)}(i)|$$

#### 【0114】

ここで、 $N_{\text{threshold}}$ は予め設定された微検索ウインドウサイズによって決定されるファクターである。その後、異なる受信アンテナのために決定される微同期位置のうちの最も早いものとなるように全体の微同期位置が取得されることが好ましい。

#### 【0115】

1つの受信アンテナのための微同期プロセスが図7-2に概略的に示されている。第1受信アンテナ736の出力において、ブロック $D^0$  738~ $D^{2N}$  742は、様々な候補微同期位置（全部で $2N+1$ 個）のためのFFTブロック744, . . . , 748のアライメントを示している。FFTブロック744, . . . , 748は、サンプルの各セットに関してFFTを計算する。各FFT出力は、各送信アンテナにおける相関器ブロックに送られる。2つの送信アンテナがある場合には、1つのFFT出力毎にそのような相関器ブロックが2つある。例えばFFT744は、第1の送信アンテナにおける第1の相関器ブロック745に対して送られる出力と、第2の送信アンテナにおける第2の相関器ブロック755に対して供給される出力とを有する。なお、トレーニングシーケンス（前述した例では、共通同期シーケンスまたはパイロットチャネルシーケンス）を送信するために副搬送波の間隔が使用される場合には、トレーニングシーケンスの構成要素を回復させるために全てのFFTを完了させる必要はない。第1のアンテナにおける相関器ブロック745は、乗算器747を用いて、FFT出力の回復されたトレーニングシーケンスシンボル位置と、第1送信アンテナにおける周知のトレーニングシーケンスとを掛け合わせ、これらの掛け算は、加算器751で加算される。第2送信アンテナの周知のトレーニングシーケンスおよび第2送信アンテナにおけるトレーニングシーケンス位置に関して、これと同じ計算が相関器755でも行なわれる。これは、各送信アンテナにおいて想定しうる異なるシフトの全てに関して、第1受信機で行なわれる。想定しうる各シフトにおける異なる送信アンテナにわたる相関結果は、乗算器753で一括して乗算される。これらの乗算の最大値を結果的に生じるシフトは、特定の受信機における微同期位置となるように選択される。任意の他の受信アンテナに関しても同じプロセスが行なわれ、また、全体の微同期位置は、そのように計算された微同期位置のうちの最も早いものとして取得されることが好ましい。

#### 【0116】

同期位置ドリフトまたはロスの場合には、フレーム毎にタイミング同期を監視することができる。例えば、前述したプリアンプルを使用するシステムにおいては、プリアンプルが受信機に達する度に、粗同期および微同期における同じ方法を使用して2段階同期プロセスが繰り返される。この場合、同期位置のドリフトが現在の位置の略近傍にあるという前提に基づいて、より小さい検索ウインドウ $N$ が使用されても良い。取得後、様々なBTSにおける専用パイロットチャネルを変調するために割り当てられた専用パイロットチャネルコードを相関器で使うことができ、または、共通同期シーケンスあるいは他の幾つかのトレーニングシーケンスを使用することができる。

#### 【0117】

複数の送信アンテナを有するMIMO-OFDM送信機に関して、本発明の一実施形態を説明してきた。OFDM送信機によって周知のトレーニングシーケンスがフレーム内に挿入されるのであれば、OFDM受信機で同期を行なう前記方法は、たった1つの送信アンテナを有するOFDM送信機から受けた信号に対して適用されても良い。

#### 【0118】

最後に、ここまで説明してきた本発明の実施形態においては、複数のアンテナを有する1つの送信機および複数のアンテナを有する1つの受信機だけが存在した。しかしながら、

本発明の概念は、多くのMIMO-OFDM送信機および多くのMIMO-OFDM受信機を有するマルチセル環境を包含するように広げられる。

#### 【0119】

##### 【マルチセル環境でのアクセス】

マルチセル環境でのシステムアクセスは、同じ共通のパイロットシンボルを送信する多くの送信機があるため、セル選択という新たな問題を招く。本発明の他の実施形態においては、先に紹介した送信ヘッダが受信機によって使用されることにより、システムアクセスおよびセル選択が行なわれる。

#### 【0120】

最初の取得中、粗同期を行なうことにより、UEが動き始める。これは、前述した方法または幾つかの他の方法を使用して行なわれても良い。1フレーム持続時間後、粗同期位置が決定される。その後、共通同期チャンネルに基づいて、微同期検索アルゴリズムが行なわれる。共通同期チャンネルによって搬送されるデータは全てのBTSにおいて同じであるため、マルチセル環境およびマルチパスフェージング伝播チャンネルにおいて幾つかのフィンガー（ピーク）を観察することができる。これらのフィンガーは、通常、異なるBTS及び／又は異なるパスに対応している。図8を参照すると、サンプルインデックスの関数としてマルチセル環境下で計算された微同期（共通同期チャンネルに対する微同期）未加工出力の一例が示されている。この例においては、5つの重要なフィンガー400, 402, 404, 406および408が存在している。M個の最も強いフィンガーが選択されるとともに、対応する位置が見つけられる。ここで、Mは、システム設計パラメータである。これらの位置は、最終同期のための候補として、また、BTS識別が成される位置として使用される。

#### 【0121】

図8の結果では、BTSが同じ共通同期シーケンスを送信するため、BTS識別を行なうことができない。想定しうる全ての隣り合うBTSの存在に関して走査するため、各候補同期位置で、受信された専用パイロットチャンネル副搬送波と、異なるBTSに対して割り当てられた想定しうる全ての複合シーケンス（専用パイロットPNシーケンス）との相関が計算される。送信アンテナが複数ある場合、好ましくはこの相関は、専用パイロット副搬送波の全てにわたって組み合わせられた複数のアンテナの専用パイロットPNシーケンスに基づいて行なわれ、これにより、インデックス毎に1つの相関結果が形成される。図9は、BTS走査結果とチェック点（候補同期位置）との間の関係の一例を示している。BTS識別は、各候補同期位置での最大相関値に対応するPNコードを検出することにより実現される。各チェック点での全ての相関結果に基づいて、C/Iを計算することができる。最初の取得段階で、最も大きいC/I比を有するBTSを選択することにより、セル選択が決定される。この例においては、2つのBTS、すなわち、第1のBTS BTS1および第2のBTS BTS2が識別される。マルチアンテナ受信機ダイバーシティを用いる場合、セル選択の最終決定は、受信機における異なる受信機アンテナによって得られる最も高いC/Iの比較に基づかなければならない。

#### 【0122】

最終同期位置を得るため、微同期が再び行なわれる。しかしながら、この場合、BTS識別によって見出された専用複合シーケンスと専用パイロットチャンネルとが使用される。微同期位置の周りで、より小さい検索ウィンドウが使用される。異なる受信機からの最終同期結果が比較される。時間的に最も早いサンプルに対応する位置が、最終同期位置として使用される。このステップは、短期フェージングに起因して弱いパス（マルチパス）が選択される可能性を減らすものである。誤りの警報の可能性を減らすため、閾値が設定される。この閾値は、検索ウィンドウ内での相関の平均および最終同期位置に対するフィンガー強度の比であっても良い。

#### 【0123】

通常のデータ処理段階においては、新たなプリアンプルを受けると、微同期ステップとBTS識別ステップとがフレーム毎に繰り返される。しかし、候補PNコードの僅かなセッ

トがBTS走査で適用される。BTS識別後、強い干渉を捜すことにより、BTS候補リストを形成することができる。このリストは、定期的に、例えば10ms毎に、更新されるとともに、BTSスイッチおよび更にはソフトハンドオフに関する情報を提供する。BTSスイッチおよびソフトハンドオフをトリガーするために、特定の基準を設定することができる。フェージングからの衝撃を平均化するため、BTS切換およびソフトハンドオフに関する決定は、特定の期間中の観察に基づいていても良い。基準は、Cを表わす最大相関値と最も強いIとの比較であっても良い。なお、セルスイッチおよびソフトハンドオフ後に、最初のアクセス時の最後のステップにより、同期が調整されても良い。全体のセル選択および再選択方法が図10に示されている。

#### 【0124】

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第1のステップ600においては、例えば時間領域のプリアンブルヘッダに基づいて、粗同期が行なわれる。これは、2つの同じシンボルを探すことにより各フレーム間で粗い境界を見つけることを含む。ピークが見つかるまで隣り合うシンボル持続時間にわたってサンプルを相関することにより、これが行なわれる。ステップ600は、2つの隣り合う同じシンボルから始まるフレームのプリアンブルに依存している。

#### 【0125】

次に、ステップ602中、粗同期ピークで、FFTが計算され、周波数領域での共通同期チャネルの処理へ切り換えられる。検索ウィンドウが同期位置+/-特定数のサンプルに中心付けられる。ステップ604により、M個の最も強い相関ピークが選択される。この時、各ピークがどのBTSに関連付けられているかは分からない。BTS識別はまだ決定されない。

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#### 【0126】

その後、ステップ606で、各相関ピーク毎に、FFTが再び計算され、専用パイロットチャネルを使用して、微同期手続きに関連付けられた相関が計算される。この場合、前記専用パイロットチャネルは、基地局固有の複合シーケンスを含む。この後、直ぐに、ステップ608が行なわれる。このステップ608では、関連する基地局の識別が行なえるように、BTS識別複合シーケンスとの相関が行なわれる。ステップ610では、このように識別されたBTS毎に、C/I比が計算される。ステップ612では、これらのC/I比に基づいて、BTS選択およびBTS切換えが行なわれる。前述したように、BTS切換えは、幾らかの時間間隔にわたって平均化されたこれらのC/I比に基づいて行なわれる。

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#### 【0127】

最後に、アクセスのため、ステップ614により、FFTが計算されるとともに、最も大きいC/I比を有するBTSの専用パイロットチャネルに対して微同期が適用される。

#### 【0128】

BTS初期同期は、共通同期チャネルにおいて行なわれる。BTS固有のシーケンスが周波数領域に組み込まれ、MIMO-OFDMチャネル間干渉を排除できる周波数領域でBTS識別処理が行なわれる。各MIMO-OFDM BTS毎に、パイロットチャネルに基づいて、BTS能力評価が行なわれる。BTS選択は、C/I比測定に基づいて行なわれる。

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#### 【0129】

このように、BTS同期とセル選択とを組み合わせることにより、過酷なマルチパスチャネル・高干渉環境下で、扱っているBTSの識別および同期を向上させることができる。チャネル評価は、共通同期チャネルと専用パイロットチャネルとを組み合わせることにより行なわれても良い。C/I評価により、セル切換え及びソフトハンドオフに関して基準が設けられる。

#### 【0130】

前述した例では、前述したプリアンブルに組み込まれたパイロットチャネルおよび同期チャネルに基づいてアクセスした。更に一般的には、任意の適当な方法でOFDMシンボリストリーム内に組み込まれたそのようなチャネルを用いてアクセスできる。

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## 【0131】

以上の説明は、本発明の原理の単なる適用例である。当業者であれば、本発明の精神および範囲から逸脱することなく、他の構成および方法を実施することができる。

## 【図面の簡単な説明】

## 【0132】

【図1-1】時間領域におけるIEEE 802.11規格のフレーム構造を示す図である。

【図1-2】周波数領域における図1-1のフレーム構造を示す図である。

【図2-1】本発明の一実施形態によって提供されるパケットデータフレームを示す図である。

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【図2-2】本発明の一実施形態によって提供されるパケットフレーム階層を示す図である。

【図3】本発明の一実施形態によって提供される提案されたヘッダ構造を示す図である。

【図4】本発明の一実施形態によって提供される時間領域におけるプリアンブルヘッダ構造を示す図である。

【図5】本発明の一実施形態によって提供される周波数領域におけるプリアンブルヘッダ構造を示す図である。

【図6】本発明の一実施形態によって提供されるMIMO-OFDM送信機の概念的な概略図である。

【図7-1】MIMO-OFDM粗同期機能のブロック図である。

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【図7-2】MIMO-OFDM微同期機能のブロック図である。

【図8】幾つかの候補同期位置を示すパイロットチャネルにおけるサインシーケンス相関出力のプロットである。

【図9】BTS識別シミュレーションのプロットである。

【図10】本発明の一実施形態によって提供されるMIMO-OFDMにおけるセル選択および再選択のための方法のフローチャートである。

## 【符号の説明】

## 【0133】

5, 13~20, 201, 203, 408, 410, 412, 414, 716, 718  
OFDMシンボル

30

9 共通同期副搬送波

10 MIMO-OFDM送信機

11 データシンボル

12 パイロットチャネル副搬送波

21 第1送信アンテナ

23 第2送信アンテナ

24 第1のOFDM部

25 パイロットチャネル副搬送波

26 第2のOFDM部

27 共通同期副搬送波

40

30 データOFDMシンボル

205 TPS OFDMシンボル

207 トレーニングOFDMシンボル

300 プリアンブル

302 分散パイロット

304 トラフィックデータシンボル

400, 402 フィンガー

404, 406, 700, 702, 704, 706, 708, 710 副搬送波

500 OFDMスーパーフレーム

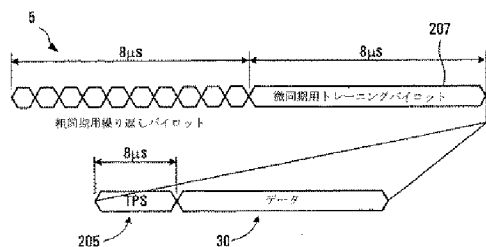
502 10ms OFDMフレーム

50

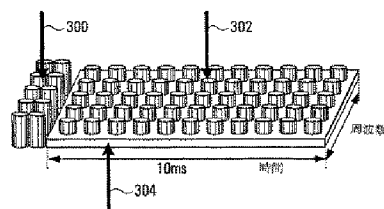
504 TPS フレーム  
 506 スロット  
 508 プリアンブル OFDM シンボル  
 510 レギュラー データ シンボル  
 603, 605, 712, 714 ヘッダ OFDM シンボル  
 607 プレフィックス  
 734 第1受信アンテナ  
 735 第2受信アンテナ  
 736 RF 受信機  
 737, 741 粗同期装置  
 738, 740, 742 ブロック  
 739 RF 受信機  
 744, 746, 748 FFT  
 745 第1の相関器ブロック  
 751 加算器  
 753 乗算器  
 755 相関器

10

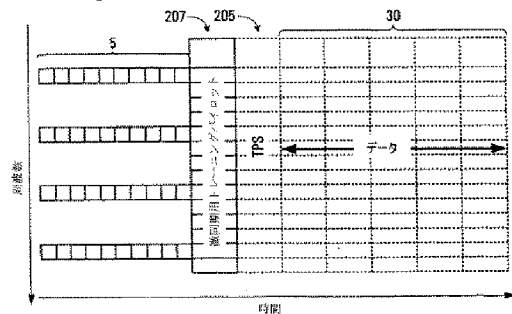
【図1-1】



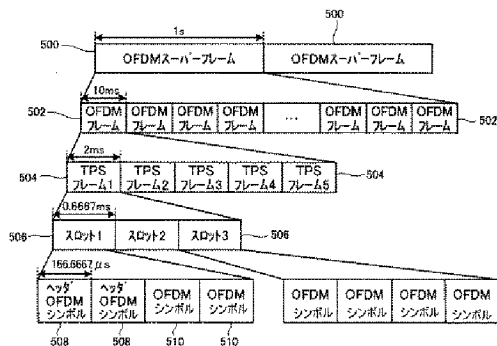
【図2-1】



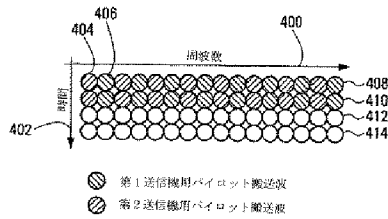
【図1-2】



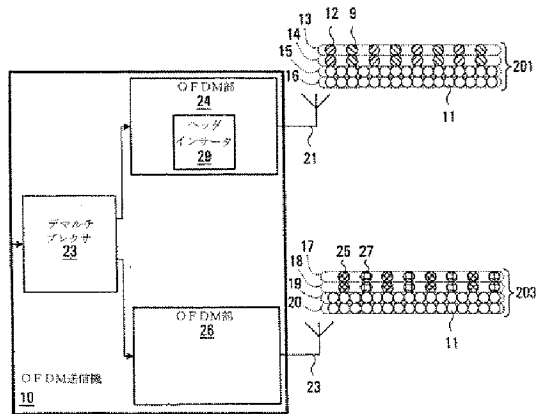
【図 2-2】



【図 3】

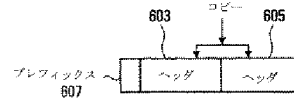


【図 6】

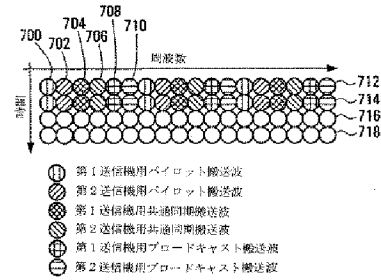


- ①・第1アンテナ用の専用パイロットチャネル
- ②・第2アンテナ用の専用パイロットチャネル
- ③・第1アンテナ用の共通同期チャネル
- ④・第2アンテナ用の共通同期チャネル

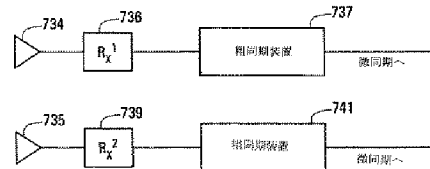
【図 4】



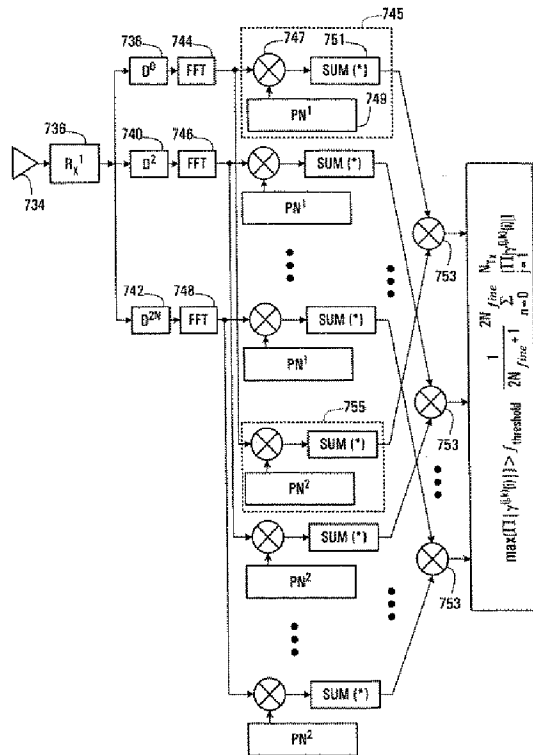
【図 5】



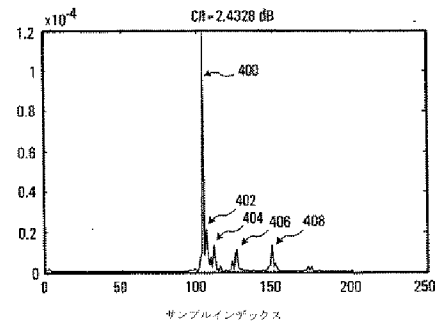
【図 7-1】



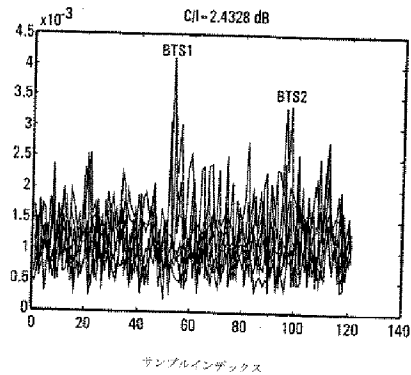
【図 7-2】



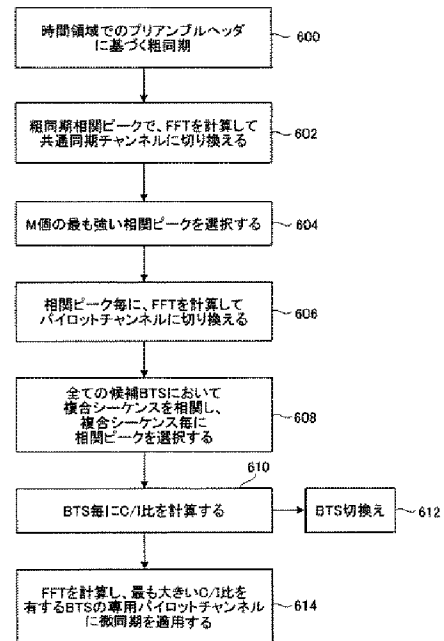
【図 8】



【図 9】



【図 10】





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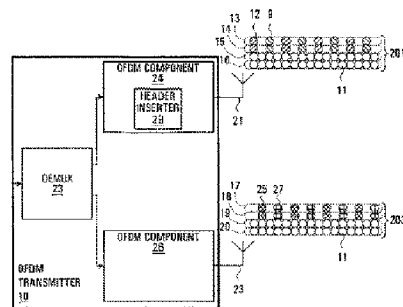
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10/038,915 8 January 2002 (08.01.2002) US(71) Applicant: NORTEL NETWORKS LIMITED  
[CA/CA]: 3351 Boulevard Alfred Nobel, St. Jap-  
rent, Quebec H8S 2A9 (CA).(72) Inventors: MA, Jiaojie; 1 Box 1280 (Chen, Kanata,  
Ontario K2M 2W5 (CA); JIA, Ming, 669-320 Chrydoo  
Avenue, Ottawa, Ontario K2B 5P3 (CA); ZHU, Peiyang;  
16 Penbie Creek Circle, Kanata, Ontario K2M 2L4 (CA);  
TONG, Wen, 12 Wallstone Drive, Ottawa, Ontario K2C  
4A7 (CA).(74) Agents: BRETT, R., Altan et al.; Soan & Biggar, 900-55  
Metcalfe Street, PO Box 2099, Station D, Ottawa, Ontario  
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(54) Title: SYSTEM ACCESS AND SYNCHRONIZATION METHODS FOR MIMO OFDM COMMUNICATIONS SYSTEMS  
AND PHYSICAL LAYER PACKET AND PREAMBLE DESIGN

(57) Abstract: A method and apparatus are provided for performing acquisition, synchronization and cell selection within an MIMO-OFDM communications system. A coarse synchronization is performed to determine a searching window. A fine synchronization is then performed by measuring correlations between subsets of signal samples, whose first signal sample lies within the searching window, and known values. The correlations are performed in the frequency domain of the received signal. In a multiple-output OFDM system, each antenna of the OFDM transmitter has a unique known value. The known value is transmitted as pairs of consecutive pilot symbols, each pair of pilot symbols being transmitted at the same subset of sub-carrier frequencies within the OFDM frame.

- ⊗ DEDICATED PILOT CHANNEL FOR ANT1
- ⊗ DEDICATED PILOT CHANNEL FOR ANT2
- ⊗ COMMON SYNCHRONIZATION CHANNEL FOR ANT1
- ⊗ COMMON SYNCHRONIZATION CHANNEL FOR ANT2

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SYSTEM ACCESS AND SYNCHRONIZATION METHODS FOR MIMO OFDM  
COMMUNICATIONS SYSTEMS AND PHYSICAL LAYER PACKET AND  
PREAMBLE DESIGN

FIELD OF THE INVENTION

5           This invention relates to cellular wireless communication systems, and more particularly to system access within cellular wireless communication systems employing OFDM or OFDM-like technology, and to physical layer packet and preamble designs.

10 BACKGROUND OF THE INVENTION

          In a wireless communication system having at least one transmitter and at least one receiver, the receiver must acquire the timing of a signal transmitted by the transmitter and synchronize to it before information can be  
15       extracted from the received signal. The timing of signals transmitted from a base station, within a wireless communication system, is commonly referred to as the system timing.

          In cellular wireless communication systems  
20       employing Orthogonal Frequency Division Multiplexing (OFDM), synchronization to the timing of a signal enables the exact positioning of a Fast Fourier transform (FFT) window utilised by a receiver of the signal to extract information from the signal.

25           In any cellular wireless communication system having multiple base stations (BTS) and multiple mobile communication devices the synchronization process must occur frequently between the BTS and the mobile communication devices for the system to be operable. The mobile  
30       communication devices will simply be referred to hereinafter as UE (user equipment).

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Furthermore, each BTS defines a geographic transmission region, known commonly as a cell, in which UE in substantially close proximity to a particular BTS will access the wireless communication system. The process  
5 whereby a particular UE selects a BTS from which to access the cellular wireless communication system is known as cell selection. In order to optimize the reception of the BTS signal, the UE needs to identify the best quality signal received from different BTSs and switch its receiver to tune  
10 into the best BTS for a given time. Thus, due to the mobility of UE, the synchronization process has to be employed frequently in order to allow seamless handoffs from one BTS to another BTS as the UE changes location.

In most current cellular wireless communication  
15 systems, fast system access and cell selection are essential functions for proper mobile UE operation. The objective of fast acquisition is to allow UE to synchronize into the desired BTS. The cell selection and re-selection is performed by UE to synchronize and measure the signal  
20 (including the interference) power among the adjacent BTS and select and switch to the BTS with the best signal quality, namely the maximum C/I (carrier-to-interference) ratio.

Existing solutions to access a wireless  
25 communication system employing OFDM (Orthogonal Frequency Division Multiplexing) were designed for wireless LAN (local area network) systems for fast packet access under a SISO (single input - single output) configuration. However, the wireless LAN does not have the capability to deal with the  
30 UE mobility, which requires seamless BTS handoff. On the other hand some cellular systems e.g. 3G UMTS are capable of performing cell selection and BTS identification and BTS C/I ratio measurement.

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Multiple Input Multiple Output - Orthogonal Frequency Division Multiplexing (MIMO-OFDM) is a novel highly spectral efficient technology used to transmit high-speed data through radio channels with fast fading both in frequency and in time. For a high-speed downlink packet data transmission system, the design of the physical layer packet structure is a fundamental aspect.

OFDM technology has been adopted by DAB, DVB-T and IEEE 802.11 standards. DAB and DVB-T are used for audio and video territorial broadcasting. In these systems, the signal is transmitted in a continuous data stream. A preamble is not needed because fast packet access is not critical. DAB and DVB-T are also applied in single frequency networks. In this case, every transmitter transmits the same signal as a simulcast. The interference from the neighbouring transmitters can be treated as an active echo, which can be handled by the proper design of the prefix. IEEE 802.11 is the wireless LAN standard. It is a packet based OFDM transmission system. A preamble header is introduced in this standard.

Synchronization within MIMO-OFDM (Multiple Input Multiple Output-OFDM) systems, in which each transmitter and each receiver have multiple antennae, is even more difficult. Adding to the complexity of the task is that a fast synchronization process must be very reliable at very low C/I ratio conditions to allow a high rate of success for the entire cell. In addition, high mobility causes a high Doppler spread and this makes reliable synchronization even more difficult.

In MIMO-OFDM systems, synchronization can be performed in two steps. First, frame synchronization (also called coarse synchronization) is performed in order to determine the approximate range of the location of the

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starting position of the first OFDM symbol in the frame.  
 Second, timing synchronization (also called fine  
 synchronization) is performed to determine the precise FFT  
 window location, so that demodulation in the frequency  
 5 domain can be performed accurately.

Conventionally, fine synchronization is  
 implemented in time domain. This is achieved by inserting an  
 a priori known pilot training sequence in the time domain  
 for the receiver to perform the cross correlation computing  
 10 at select time slots.

For example, as shown in Figures 1A and 1B, the  
 OFDM frame structure of the IEEE 802.11 standard utilizes  
 several repeated short OFDM symbols generally indicated at 5  
 arranged as several headers in the time domain at the  
 15 beginning of the frame for select sub-carriers, followed by  
 training OFDM symbols 207 for fine synchronization. The  
 headers 5 are used for frame (i.e. course) synchronization.  
 The training OFDM symbols 207 are used to position the FFT  
 window precisely so that demodulation in the frequency  
 20 domain can be performed accurately. The training OFDM  
 symbols 207 are followed by a TPS OFDM symbol 205 and data  
 OFDM symbols 30.

The TPS (transmission parameter signalling) OFDM  
 symbol 205, shown more clearly in the frequency domain (see  
 25 Figure 1B), is transmitted with a frequency that corresponds  
 to an adaptive coding and modulation period. The training  
 OFDM symbols, TPS OFDM symbol and data OFDM symbols use all  
 sub-carriers. In the 802.11 system, the repeated headers  
 for course synchronization are only transmitted on every  
 30 fourth sub-carrier. This design is only suitable for a  
 simple SISO OFDM system with only a single transmit antenna.  
 For MIMO-OFDM system the preamble design is more complicated  
 because of the existence of multiple transmit antennas.

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Furthermore for mobile communications, an efficient preamble design is even more difficult because of the multi-cell environment, the requirement for initial access when no BTS information is available, BTS switching and even soft  
5 handoff.

Existing methods in the process of cell acquisition and synchronization employ a 3-step-synchronization approach adopted by UMTS WCDMA system, which requires a relatively long access time. While fine  
10 synchronization may be performed in the time domain, the self-interference of MIMO channels limits the performance of this approach under very low C/I conditions. Increasing the length of the correlation can enhance the performance of fine synchronization in the time domain but at the price of  
15 an increase in overhead and processing complexity. The existing designs are based on the time domain training sequence correlation for a single transmit antenna and a single receive antenna system. However, a straightforward extension of such a time domain synchronization approach  
20 will cause performance loss especially for low C/I ratio applications. The cause of the performance loss is the self-interference between the MIMO channels that is not easy to reduce in time domain.

#### 25 SUMMARY OF THE INVENTION

One broad aspect of the invention provides a MIMO-OFDM transmitter adapted to transmit a header symbol format in which sub-carriers of a header OFDM symbol are divided into a non-contiguous set of sub-carriers for each of a  
30 plurality of antennas, with each antenna transmitting the header OFDM symbol only on the respective set of sub-carriers.

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In some embodiments, there are  $N$  antennas and a different set of sub-carriers separated by  $N$  sub-carriers is assigned to each of the plurality of antennas.

In some embodiments, the header symbols contain a  
5 multiplexed dedicated pilot channel on dedicated pilot  
channel sub-carriers and common synchronization channel on  
common synchronization channel sub-carriers for each of the  
plurality of antennas.

In some embodiments, the header OFDM symbols  
10 further contain multiplexed broadcasting sub-carriers for  
each of the plurality of antennas.

In some embodiments, the transmitter is further  
adapted to transmit a preamble having a prefix, followed by  
two identical OFDM symbols having said header OFDM symbol  
15 format. In some embodiments, the prefix is a cyclic  
extension of the two identical OFDM symbols.

In some embodiments, the pilot channel has a BTS  
specific mapped complex sequence allowing efficient BTS  
identification.

20 In some embodiments, the common synchronization  
channel is designed for fast and accurate initial  
acquisition.

In some embodiments, the common synchronization  
channel is used for course synchronization and fine  
25 synchronization and the pilot channel is used for fine  
synchronization.

In some embodiments, the common synchronization  
channel is used to transmit a complex sequence which is  
different for each transmit antenna of one transmitter, but  
30 which is common for respective transmit antennas of  
different transmitters within a communications network.



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In some embodiments, the transmitter is further adapted to transmit OFDM frames beginning with said preamble, and having scattered pilots throughout a remainder of the OFDM frame.

5 In some embodiments, during the preamble, for each of N transmit antennas, dedicated pilot channel sub-carriers are transmitted and common synchronization channel sub-carriers are transmitted and broadcasting channel sub-carriers are transmitted.

10 In some embodiments, the sub-carriers of the preamble OFDM symbols are organized as a repeating sequence of {dedicated pilot channel for each of N transmit antennas, common synchronization channel sub-carrier for each of N transmit antennas} arranged in a predetermined order.

15 In some embodiments, the sub-carriers of the preamble OFDM symbols are organized as a repeating sequence of {at least one dedicated pilot channel sub-carrier for each of N transmit antennas, at least one common synchronization channel sub-carrier for each of N transmit antennas, at least one broadcast channel sub-carrier}  
20 arranged in a predetermined order.

Another broad aspect of the invention provides a MIMO-OFDM receiver adapted to receive a header symbol format in which sub-carriers of a header OFDM symbol are divided  
25 into a non-contiguous set of sub-carriers for each of a plurality of antennas, with each antenna transmitting the header OFDM symbol only on the respective set of sub-carriers.

In some embodiments, the receiver is adapted to  
30 receive from N transmit antennas with a different set of sub-carriers separated by N sub-carriers assigned to each of the plurality of transmit antennas.

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In some embodiments, the receiver is further adapted to perform fine synchronization on the basis of the common synchronization channel sub-carriers and/or the dedicated pilot channel sub-carriers.

5 Another broad aspect of the invention provides a transmitter adapted to transmit a packet data frame structure. The packet data frame structure has a superframe having a length corresponding to a synchronization period of a network; the superframe containing a plurality of radio  
10 frames; each radio frame containing a plurality of TPS (transmission parameter signalling) frames corresponding to an adaptive coding and modulation period; each TPS frame containing a plurality of slots corresponding to an air interface slot size; each slot containing a plurality of  
15 OFDM symbols, with the first two symbols of the first slot of the first TPS frame of each OFDM frame being used as header OFDM symbols.

In some embodiments, the header OFDM symbols have a header OFDM symbol format in which sub-carriers of a  
20 header OFDM symbol are divided into a non-contiguous set of sub-carriers for each of a plurality of antennas, with each antenna transmitting the header OFDM symbol only on the respective set of sub-carriers.

In some embodiments, the header OFDM symbols  
25 contain multiplexed pilot channel sub-carriers and common synchronization channel sub-carriers for each of the plurality of antennas.

In some embodiments, the header OFDM symbols further contain multiplexed broadcasting channel sub-  
30 carriers for each of the plurality of antennas.

In some embodiments, the transmitter is further adapted to transmit in a plurality of different modes by

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transmitting a different number of OFDM symbols per slot with an unchanged slot duration and with no change to the frame structure above the slot.

In some embodiments, wherein modes with an increased number of OFDM symbols per slot are realized by shortening OFDM symbol duration, and shortening FFT size, but not changing sampling frequency.

In some embodiments, the transmitter is further adapted to transmit to a respective set of users for each TPS frame and to signal for each TPS frame which users should demodulate the entire TPS frame.

Another broad aspect of the invention provides a method of performing synchronization at an OFDM receiver. The method involves, at each of at least one receive antenna, sampling a received signal to produce a respective set of time domain samples; determining at least one course synchronization position; at each of the at least one receive antenna:

- a) for each of a plurality of candidate fine synchronization positions about one of said at least one course synchronization position:
  - i) for each receive antenna positioning an FFT window to the candidate fine synchronization position and converting by FFT the time domain samples into a respective set of frequency domain components;
  - ii) for each said at least one transmit antenna, extracting a respective received training sequence corresponding to the transmit antenna from the sets of frequency domain components;
  - iii) for each transmit antenna, calculating a correlation between each respective received

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training sequence and a respective known transmit training sequence;

iv) combining the correlations for the at least one transmit antennas to produce an overall correlation result for each candidate synchronization position;

b) determining a fine synchronization position from the plurality of correlation values;

combining the fine synchronization positions from the at least one receive antenna in an overall fine synchronization position.

In some embodiments, a course synchronization position is determined for each receive antenna and used for determining the respective fine synchronization position.

In some embodiments, a course synchronization position is determined for each receive antenna and an earliest of the positions is used determining the fine synchronization positions for all receive antennas.

In some embodiments, the course synchronization position is determined in the time domain for at least one receive antenna by looking for a correlation peak between the time domain samples over two OFDM symbol durations.

In some embodiments, the method is applied at an OFDM receiver having at least two antennas, and combining the fine synchronization positions from the at least one receive antenna in an overall fine synchronization position comprises selecting an earliest of the fine synchronization positions.

In some embodiments, sampling a received signal to produce a set of time domain samples is done for at least three OFDM symbol durations; determining at least one course synchronization position comprises performing a

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course synchronization in the time domain by looking for a correlation peak between the time domain samples received over two OFDM symbol durations to identify a course synchronization position by:

- 5           a)           calculating a plurality of correlation values, each correlation value being a correlation calculated between a first set of time domain samples received during a first period having one OFDM symbol duration and a second set of time domain samples received  
10           during a second period immediately following the first period and having OFDM symbol duration, for each of a plurality of starting times for said first period;
- b)           identifying the course synchronization position to be a maximum in said plurality of correlation  
15           values.

          In some embodiments, combining the correlations for the at least one transmit antennas to produce an overall correlation result for each candidate synchronization position comprises multiplying together the correlations for  
20           the at least one transmit antenna for each candidate synchronization position.

          In some embodiments, the method is applied to a single transmit antenna single receive antenna system.

          In some embodiments, the training sequence is  
25           received on common synchronization channel sub-carriers.

          In some embodiments, the training sequence is received during an OFDM frame preamble.

          In some embodiments, the training sequence is received on dedicated pilot channel sub-carriers.

30           In some embodiments, the training sequence is received during an OFDM frame preamble.

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Another broad aspect of the invention provides an OFDM receiver having at least one receive antenna; for each said at least one receive antenna, receive circuitry adapted to sample a received signal to produce a respective set of time domain samples; a course synchronizer adapted to determine at least one course synchronization position; a fine synchronizer comprising at least one FFT, at least one correlator and at least one combiner, adapted to, at each of the at least one receive antenna:

10           a)           for each of a plurality of candidate fine synchronization positions about one of said at least one course synchronization position:

              i)           for each receive antenna position an FFT window to the candidate fine synchronization position and convert by FFT the time domain samples into a  
15           respective set of frequency domain components;

              ii)          for each said at least one transmit antenna, extract a respective received training sequence corresponding to the transmit antenna from the sets  
20           of frequency domain components;

              iii)       for each transmit antenna, calculate a correlation between each respective received training sequence and a respective known transmit training sequence;

25           iv)       combine the correlations for the at least one transmit antennas to produce an overall correlation result for each candidate synchronization position;

              b)           determine a fine synchronization  
30           position from the plurality of correlation values;

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the receiver being further adapted to combine the fine synchronization positions from the at least one receive antenna in an overall fine synchronization position.

In some embodiments, the receiver has at least two  
5 receive antennas, and is adapted to combine the fine synchronization positions from the at least one receive antenna in an overall fine synchronization position by selecting an earliest of the fine synchronization positions.

In some embodiments, the receiver is adapted to  
10 combine the correlations for the at least one transmit antennas to produce an overall correlation result for each candidate synchronization position by multiplying together the correlations for the at least one transmit antenna for each candidate synchronization position.

15 In some embodiments, the receiver is adapted to receive the training sequence on common synchronization channel sub-carriers.

In some embodiments, the receiver is adapted to receive the training sequence on dedicated pilot channel  
20 sub-carriers.

Another broad aspect of the invention provides a method of performing fine synchronization. The method involves, at each at least one receive antenna receiving OFDM symbols containing a respective received frequency  
25 domain training sequence for each of at least one transmit antenna; performing fine synchronization in the frequency domain by looking for maximum correlations between known frequency domain training sequences and the received frequency domain training sequences.

30 Another broad aspect of the invention provides a method of transmitting signals enabling fine synchronization. The method involves from each of at least

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one transmit antenna, transmitting OFDM symbols containing a respective frequency domain training sequence.

In some embodiments, a different frequency domain training sequence is transmitted by each transmit antenna, but the same frequency domain training sequence is transmitted by corresponding antenna of other transmitters.

Another broad aspect of the invention provides a method of performing cell selection at an OFDM receiver. The method involves at each of at least one receive antenna, sampling a received signal to produce a respective set of time domain samples; determining at least one coarse synchronization position; at each of the at least one receive antenna:

- a) performing a frequency domain correlation between at least one received common synchronization sequence extracted from common synchronization channel sub-carriers in the received signal and a corresponding common synchronization sequence of a respective plurality of transmit antennas to identify a plurality of candidate correlation peaks;
- b) selecting the M strongest correlation peaks for further processing;
- c) at each correlation peak, reconvertng time domain samples into frequency domain components and processing pilot channel sub-carriers, these containing transmitter specific information, to identify a transmitter associated with each correlation peak;
- d) determining a C/I or similar value for each transmitter thus identified;
- e) selecting the transmitter having the largest C/I determined for any of the at least one receive antenna.



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In some embodiments, performing a frequency domain correlation between at least one received common synchronization sequence extracted from common synchronization channel sub-carriers in the received signal  
5 and a corresponding common synchronization sequence of a respective plurality of transmit antennas to identify a plurality of candidate correlation peaks comprises:

a) for each of a plurality of candidate fine synchronization positions about one of said at least  
10 one coarse synchronization position:

i) for each receive antenna  
positioning an FFT window to the candidate fine synchronization position and converting by FFT the time domain samples into a respective set of frequency domain  
15 components;

ii) for each of at least one common synchronization sequence, each common synchronization sequence having been transmitted by a transmit antenna of each of at least one transmitter, extracting a respective  
20 received training sequence corresponding to the transmit antennas from the sets of frequency domain components;

iii) for each of the at least one common synchronization sequence, calculating a correlation between each respective received common synchronization  
25 sequence and a respective known common synchronization sequence;

iv) combining the correlations to produce an overall correlation result for each candidate synchronization position;

30 b) determining at least one peak in the correlations, each said at least one peak being local maxima in the correlations.

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In some embodiments, the method further involves reconvert-  
ing time domain samples into frequency domain components based on the fine synchronization position of the selected transmitter and performing a further fine  
5 synchronization based on a dedicated pilot channel for that transmitter.

In some embodiments, the method is applied to a MIMO-OFDM frame format having a header symbol format in which subcarriers of a header symbol are divided into a non-  
10 contiguous set of subcarriers for each of a plurality of antennas, with each antenna transmitting header symbols only on the respective set of sub-carriers, and wherein the header symbols contain multiplexed pilot channel sub-carriers and common synchronization channel sub-carriers for  
15 each of the plurality of antennas, the frame beginning with two identical header OFDM symbols during which contents of the pilot channel sub-carriers are repeated and contents of the synchronization channel sub-carriers are repeated, the common synchronization channel sub-carriers carrying a  
20 complex sequence which is different for respective antenna of one base station and being common across multiple base stations, and contents of the dedicated pilot channel sub-carriers being at least locally unique to a particular base station.

25 In some embodiments, the method further involves for transmitter switching, averaging the C/I or similar value over a time interval for each transmitter thus identified, and at the end of the time interval instigating a transmitter switch to the transmitter with the largest  
30 average C/I or similar value if different from a currently selected transmitter.

BRIEF DESCRIPTION OF THE DRAWINGS

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Preferred embodiments of the invention will now be described in greater detail with reference to the accompanying diagrams, in which:

Figure 1A is the frame structure of IEEE 802.11  
5 standard in the time domain;

Figure 1B is the frame structure of Figure 1A in the frequency domain;

Figure 2A is a packet data frame structure provided by an embodiment of the invention;

10 Figure 2B is a packet frame hierarchy provided by an embodiment of the invention;

Figure 3 is a proposed header structure provided by an embodiment of the invention;

Figure 4 is a preamble header structure in the  
15 time domain provided by an embodiment of the invention;

Figure 5 is a preamble header structure in the frequency domain provided by an embodiment of the invention;

Figure 6 is a conceptual schematic view of a MIMO-OFDM transmitter provided by an embodiment of the invention;

20 Figure 7A is a block diagram of a MIMO-OFDM coarse synchronization functionality;

Figure 7B is a block diagram of a MIMO-OFDM fine synchronization functionality;

Figure 8 is a plot of a signature sequence  
25 correlation output for pilot channel showing several candidate synchronization position;

Figure 9 is a plot of a BTS identification simulation; and

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Figure 10 is a flowchart of a method for cell selection and re-selection for MIMO-OFDM provided by an embodiment of the invention.

#### 5 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to Figure 2A, an OFDM packet frame structure provided by an embodiment of the invention is shown. Transmit OFDM symbol streams are organized into such frames. Each frame consists of three major components:  
 10 preamble 300, scattered pilots 302, and traffic data symbols 304. The insertion of the preamble allows UE (user equipment) to perform the following fundamental operations: fast BTS (base station) access, BTS identification and C/I ratio measurement, framing and timing synchronization,  
 15 frequency and sampling clock offset estimation and initial channel estimation. The design of a frame preamble with minimized overhead is critical to maximum spectral efficiency and radio capacity.

Referring now to Figure 2B, a frame hierarchy for  
 20 MIMO-OFDM is organized according to an embodiment of the invention as follows: at the highest level are OFDM superframes 500 (two shown). The duration of the superframe is determined by the network synchronization period (for example 1-second). The superframe is composed of several 10  
 25 ms radio frames 502 also referred to as OFDM frames. There would be 100 10 ms OFDM frames 502 in a 1s superframe 500.

To support adaptive coding modulation (ACM), a fast signalling channel (TPS channel-transmission parameter signalling) is introduced. Each OFDM frame 502 is  
 30 subdivided into TPS frames 504, in the illustrated example there are five 2 ms TPS frames for each 10 ms radio frame 502. The frame length used for TPS in some embodiments is

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the same as the duration of the ACM unit. Each TPS frame also contains signalling information which allows each user to determine whether the current TPS frame contains data for them or not. A TPS frame may contain data for multiple  
 5 users.

The TPS frame 504 can be divided further into several slots 506, each of which consists of several OFDM symbols. In the illustrated example, each TPS frame 504 is subdivided into 3 slots 506. The duration of the slot 506  
 10 depends upon the air interface slot size. The smallest transmission unit is one OFDM symbol 508, 510. The duration of one OFDM symbol is determined by the transmission environment characteristics, for example, the maximum channel delay, the system-sampling clock and the maximum  
 15 Doppler. In the illustrated example, there are four OFDM symbols 508, 510 per slot 506.

To reduce the overhead caused by the insertion of the guard interval between OFDM symbols, different OFDM symbol modes each with a different symbol duration and a  
 20 different prefix can be designed, for example, 0.5k mode and 1k mode. To simplify the system the sampling frequency is kept unchanged when doing the mode switching. These different modes are described in more detail below.

The frame structure of Figure 2B gives an example  
 25 of a frame structure hierarchy compatible to the UMTS air-interface. At the OFDM symbol level, there are two different types of OFDM symbols. These include the preamble OFDM symbols 508 and regular data symbols 510.

Referring now to Figure 4, which is a time domain  
 30 representation, each OFDM frame starts with a preamble, which consists of several identical header OFDM symbols 603, 605 preceded by a prefix 607 which is a cyclic extension of the header OFDM symbols. A repetition structure is used to

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assist synchronization. By performing a correlation between adjacent OFDM symbols until two identical symbols are identified, the start of an OFDM frame can be found. By way of example, there may be 1056 samples used per OFDM symbol.

5 For the preamble, during the prefix 607, the last 64 samples of the header OFDM symbols are transmitted. There is no prefix for the second header OFDM symbol. The header is inserted periodically, and for the example of Figure 2B, this occurs every 10 ms, i.e. at the beginning of every OFDM

10 frame.

Referring again to Figure 2B, it is noted that for non-header OFDM symbols, i.e. for the regular OFDM symbols 510, every OFDM symbol preferably also has a prefix. In "1K" mode, there are 32 prefix samples, and 1024 actual

15 samples representing the FFT size, for a total of 1056 samples per symbol. In 1/2K mode, there is a 16 sample prefix, and then 512 samples per symbol (representing the FFT size) for a total of 528 samples/symbol.

Advantageously, using the frame structure of Figure 2B these

20 different modes can be supported without changing the sampling frequency. When in 1/2K mode, there are twice as many OFDM symbols 510 per slot 506. The particular mode chosen at a given instant should be such that the prefix size is greater than the maximum channel delay. In 1/K

25 mode, more OFDM symbols are sent with fewer sub-carriers. This is more robust to high Doppler, because the symbol duration is shorter. Also, the spacing between the sub-carriers is larger further enhancing tolerance to Doppler.

Thus, there is a unified frame structure which accommodates

30 different FFT sizes, but with the same sampling rate at the receiver. Preferably the same preamble is used even for the different modes.

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OFDM is a parallel transmission technology. The whole useful bandwidth is divided into many sub-carriers, and each sub-carrier is modulated independently. According to an embodiment of the invention, to separate different antenna with multiple antennas transmission, during the header not all sub-carriers are used on all transmit antennas. Rather, the sub-carriers are divided between antennas. An example of this will now be described with reference to Figure 3. The sub-carrier frequencies contained within an OFDM symbol are each represented by circles. In this example it is assumed that there are two transmitting antennas in the MIMO system. Figure 3 shows OFDM symbols with the various sub-carriers spaced along the frequency axis 400, and with the contents of all the sub-carriers at a given instant representing one symbol in time, as indicated along the time axis 402. In this case, the first two OFDM symbols 408, 410 are used for dedicated pilot channel information while the remaining symbols (only two shown, 412, 414) are used for regular OFDM symbols. The dedicated pilot channel information transmitted on the first two OFDM symbols 408, 410 alternates by sub-carrier between being transmitted by the first antenna and the second antenna. This is indicated for the first sub-carrier 404 which is transmitting dedicated pilot channel information for the first transmitter and sub-carrier 406 which is transmitting dedicated pilot channel information for the second sub-carrier, and this pattern then repeats for the remainder of the sub-carriers. The other OFDM symbols 412, 414 contain information transmitted by both antennas. It is to be understood that other spacings could alternatively be used. Furthermore, if there are more than two transmit antennas, the pilot channel information would then alternate by sub-carrier in some predetermined pattern between all of the transmit antennas.

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In another embodiment, a common synchronization channel, and dedicated pilot channel are frequency multiplexed onto the header symbols. A respective set of non-overlapping sub-carriers are assigned for each antenna  
5 to transmit respective dedicated pilot channel and common synchronization channel.

In another embodiment a common synchronization channel, dedicated pilot channel and a broadcasting channel are frequency multiplexed onto the header symbols. Under  
10 this arrangement, the total useful sub-carriers of the header symbols are separated into three groups. These three groups are mapped onto the common synchronization channel, dedicated pilot channel and the broadcasting channel respectively.

An example of the mapping of the different channels in the MIMO-OFDM system with two-transmitter diversity is shown in Figure 5. In this example, there are shown four OFDM symbols 712, 714, 716, 718 two of which 712, 714 are header symbols. During the header symbols 712, 714  
20 every second sub-carrier is used for the first antenna with the remaining sub-carriers used for the second antenna. This is easily generalized to higher numbers of antennas. For this example, it is assumed that there are two transmit antennas in the MIMO system. Every sixth sub-carrier  
25 starting at the first sub-carrier 700 is for the first transmitter dedicated pilot channel sub-carriers. Every sixth sub-carrier starting at the second sub-carrier 702 is for the second transmitter dedicated pilot channel sub-carrier. Every sixth sub-carrier starting at the third sub-  
30 carrier 704 is for the first transmitter common synchronization channel sub-carrier. Every sixth sub-carrier starting at the fourth sub-carrier 706 is for the second transmitter common synchronization channel sub-



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carrier. Every sixth sub-carrier starting at the fifth sub-carrier is for broadcasting channel sub-carriers for the first antenna, and every sixth sub-carrier starting at the sixth sub-carrier 710 is for broadcasting channel sub-carriers for the second antenna.

The common synchronization channel is a universal channel for initial access. It can also be used for synchronization and preliminary channel estimation. The different transmitters share the common synchronization sub-carriers when transmitter diversity is applied. In which case as indicated above the common synchronization channel is divided between different transmitters. A common complex sequence known by all the terminals is used to modulate the sub-carriers reserved for the common synchronization channel. The same common synchronization sequence is transmitted by all base stations within a system. There may be one or more such synchronization sequences in the event that there are multiple transmit antennas such that each transmit antenna can transmit a unique synchronization sequence. Using the synchronization sequence, mobile stations are able to find initial synchronization positions for further BTS identification by looking for a correlation peak between received synchronization sequence and the known transmitted synchronization sequence.

The dedicated pilot channel is used for BTS/cell identification, and supports C/I measurement for the cell selection, cell switching and handoff. A unique complex sequence, for example a PN code, is assigned to each BTS and used to modulate the dedicated pilot sub-carriers. A different unique sequence is transmitted by each antenna in the multiple transmit antenna case. Unlike the case for the common synchronization channel, different base stations transmit using different pilot sequences. The quasi-

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orthogonality of the PN codes assigned to different BTSs makes it possible to do access point identification and initial interference measurement. The dedicated pilot channel can also be used to assist the synchronization processing.

To fully utilize the sub-carriers in the header OFDM symbols, as indicated above, some sub-carriers are preferably used as a broadcasting channel. In the example of Figure 5, two of every six sub-carriers are used for this purpose. The broadcasting channel can carry important system information. STTD (space time transmit diversity) schemes cannot be used for the broadcasting channel (or any of the sub-carriers in the header OFDM symbols) because of it will destroy the repetition structure of the header OFDM symbols which is required by synchronization algorithms. However transmitting the broadcasting information by all transmitters on the same sub-carrier may cause destructive interference between transmitters. To solve that problem the broadcasting channel is partitioned between different transmitters, so in the two transmit antenna case, the sub-carriers (mapped for the broadcasting channel) can be assigned alternatively for the transmit antenna to provide diversity. Power boosting may be applied to further enhance the broadcasting channel.

The broadcasting information from different BTS's can be different. In some embodiments broadcasting information is protected so those users close to the cell boundaries can receive it correctly in the presence of strong interference. A short PN code could be used to spread the broadcasting information. The neighbouring BTS is assigned to use different code. The insertion of the broadcasting channel reduces the preamble overhead and increases the spectrum efficiency.

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The broadcast channel is used to transmit information unique to the particular base station. A single broadcast message may be sent on the combined broadcast channel carriers for the two antennas. By designing the preamble header symbol to consist of pilot channel, synchronization channel and the broadcasting channel, the preamble header overhead is reduced. The common synchronization channel is designed for fast and accurate initial acquisition. The dedicated pilot channel with a BTS specific mapped signature allows an efficient BTS identification. The combined common synchronization channel and the pilot channel are used together for MIMO channel estimation. The use of the combined common synchronization channel and the dedicated pilot channel also allows for high accuracy synchronization. Frequency domain training symbols are robust to timing error and multipath environments. The preamble design allows the flexibility of the user equipment to implement more efficient algorithms.

It is noted that the specific breakdown of sub-carriers between the dedicated pilot channel in one embodiment, between the dedicated pilot channel and common synchronization channel in another embodiment, and between the dedicated pilot channel, common synchronization channel and broadcast channels in another embodiment, are only specific examples. These can be allocated in any suitable manner.

Referring now to Figure 5, shown is a conceptual schematic of a MIMO-OFDM transmitter 10. A first sample set of four OFDM symbols 201 is shown transmitted from a first transmit antenna 21 and a second sample set of four OFDM symbols 203 is shown transmitted from a second transmit antenna 23. In general an OFDM transmitter will have  $N_{ant}$  transmit antennae, where  $N_{ant}$  is a design parameter. Within

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the MIMO-OFDM transmitter 10, data originating from a demultiplexer 23 are sent to one of either a first OFDM component 24 connected to transmit antenna 21 or a second OFDM component 26 connected to transmit antenna 23. The components organize the data onto sub-carriers of OFDM symbols and OFDM frames, each sub-carrier being at a different orthogonal frequency. Each OFDM component 24, 26 has a respective header inserter 29 which inserts header OFDM symbols. The sample sets of OFDM symbols 201 and 203 represent the first four OFDM symbols of the transmitted OFDM frame from transmit antennae 21 and 23, respectively, where each row of data symbols or pilot symbols is an OFDM symbol. A first OFDM symbol 13 and a second (identical to the first) OFDM symbol 14 represent the two header OFDM symbols unique to the OFDM frame transmitted by first transmit antenna 21. Similarly, a third OFDM symbol 17 and a fourth (identical to the third) OFDM symbol represent the two header OFDM symbols unique to the OFDM frame transmitted by the second transmit antenna 23. Four OFDM symbols 15, 16, 19, 20 are typically non-identical OFDM symbols made up of a plurality of data symbols, with at least one data symbol indicated generally at 11 on each OFDM sub-carrier. An entire OFDM frame would typically have many more data symbols. Also, the OFDM symbols 201 are transmitted concurrently, and with the same timing, as OFDM symbols 203.

In this example, the two identical header OFDM symbols consist of dedicated pilot channel sub-carriers 12 and common synchronization channel sub-carriers 9. There may also be broadcast channel sub-carriers, not shown. The dedicated pilot channel sub-carriers are used for C/I ratio measurement and BTS identification and fine synchronization as detailed below; they can also be used for initial channel estimation. The common synchronization channel sub-carriers 9 are used for course synchronization and fine

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synchronization, initial access, and initial channel estimation.

In the illustrated example, during the two header OFDM symbols, the first of every four consecutive sub-carriers is used to carry dedicated pilot channel symbols transmitted by transmitting antenna 21. Similarly, the second of every four consecutive sub-carriers is used to carry dedicated pilot channel symbols transmitted by transmitting antenna 23.

10 The dedicated pilot channel symbols transmitted on the pilot channel sub-carriers 12, 25 are defined by base station/sector specific PN sequence. A set of symbols from a complex pseudo-random PN sequence unique to the base station is mapped onto the dedicated pilot channel sub-carrier locations in the header OFDM symbols.

15 The third of every four consecutive sub-carriers in the two header symbols is used to carry common synchronization channel symbols transmitted by transmitting antenna 21. Similarly the fourth of every four consecutive sub-carriers is used to common synchronization channel symbols transmitted by transmitting antenna 23.

The common synchronization channel symbols transmitted on the common synchronization sub-carriers 9, 27 are defined by unique complex pseudo-random PN sequence for each transmit antenna 21 and 23. A set of symbols from this complex pseudo-random PN sequence is mapped onto the common synchronization channel sub-carriers in the header OFDM symbols. That is, the common synchronization channel symbols of each frame transmitted through each transmitting antenna use a PN code unique to that transmitting antenna but which is the same for corresponding transmitting antennas of other base stations. In the present example  $PN_{sync}^{(1)}$  is associated with transmit antenna 21 and  $PN_{sync}^{(2)}$  is

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associated with transmit antenna 23. However, similar antennae in different transmitters throughout the communication network will use the same PN code. For example, the common synchronization channel symbols for a first transmit antenna 21 on all transmitters within the network will use one PN code ( $PN_{sync}^{(1)}$ ), and the common synchronization channel symbols for a second transmit antenna 22 on all transmitters within the network will use a different PN code ( $PN_{sync}^{(2)}$ ).

Referring to Figure 7A, a block diagram of MIMO-OFDM receiver functionality is shown which is adapted to perform coarse synchronization based on the two repeated OFDM header symbols transmitted by each transmit antenna as detailed above. The OFDM receiver includes a first receiving antenna 734 and a second receiving antenna 735 (although more generally there will be a plurality of  $N$  receiving antennae). The first receiving antenna 734 receives a first received signal at RF receiver 736. The first received signal is a combination of the two signals transmitted by the two transmitting antennae 21 and 23 of Figure 6, although each of the two signals will have been altered by a respective channel between the respective transmitting antenna and the first receiving antenna 734. The second receiving antenna 735 receives a second received signal at RF receiver 739. The second received signal is a combination of the two signals transmitted by the two transmitting antennae 21 and 23, although each of the two signals will have been altered by a respective channel between the respective transmitting antenna and the second receiving antenna 735. The four channels (between each of the two transmitting antennae and each of the two receiving antennae) may vary with time and with frequency, and will in general be different from each other.

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Coarse synchronization is performed for the first receive antenna 734 by a coarse synchronizer 737 on discrete time samples of a received signal to determine an approximate range of a location of the starting position of the first header symbol. A similar process is performed by course synchronizer 741 for the second antenna 735. Coarse synchronization is facilitated by the use of repeated header symbols at the OFDM transmitter. The coarse synchronizer 737 performs correlation measurements on time domain signal samples in successive OFDM symbols. The time domain signal sample yielding the highest correlation measurement is the coarse synchronization position  $n_{\text{coarse}}$ . The course synchronization position  $n_{\text{coarse}}$  is then used as the position on which to locate an FFT window within the FFT functions used in fine synchronization.

Initially, the coarse synchronizer 737 starts the time domain coarse synchronization processing. A running buffer (not shown) is used to buffer discrete time samples of the received signal over three successive OFDM symbol period, and then calculates the auto-correlation  $\gamma_c(n)$  between samples collected during two successive OFDM symbol durations as follows:

$$\gamma_c(n) = \sum_{i=0}^{N_{\text{header}}-1} x(n+i) x^*(n+i+N_{\text{header}})$$

where  $x(n)$  is the time domain samples of the received signal,  $N_{\text{header}}$  is the number of samples taken over one OFDM symbol duration.

In some embodiments, a moving correlator is applied in the real time implementation to save calculation power.

In one embodiment, the values of  $\gamma_c(n)$  are calculated in sequence, for  $n=1$  (until  $n = N_{\text{header}}$ ), until a

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correlation value is above a threshold, after which a maximum search is enabled. The computation of the correlation values continues and the maximum search process will continue until the correlation result is below the threshold again. The sample position corresponding to the maximum correlation value is the coarse synchronization position:

$$n_{\text{course}} = \text{argmax}(|\gamma_i(n)|) \quad n \in \{\gamma_k(n) > \gamma_{\text{threshold}}\}$$

The threshold is typically calculated from the average auto-correlation values within one frame. Alternatively, another way of finding the maximum is to determine a local maximum for each OFDM symbol over an OFDM frame which might be 60 symbols in length for example. Then, the overall maximum is taken to be the maximum of the local maxima. This process is conducted both course synchronizers. In the event fine synchronization is to proceed jointly, the overall course synchronization position may be taken as some combination of the two synchronization values, and is preferably taken to be the earlier of two course synchronization positions thus determined. Alternatively, each fine synchronizer (detailed below) can work from a respective course synchronization position. Referring to Figure 7B, a block diagram is shown of an MIMO-OFDM fine synchronization functionality is shown. In one embodiment, the fine synchronization functionality is adapted to perform fine synchronization based on the two-repeated OFDM header symbols transmitted by each transmit antenna as detailed above using the common synchronization channel and/or the dedicated pilot channel. More generally, the fine synchronization functionality can perform fine synchronization for OFDM frames within which some known training sequence has been embedded. Also, an input to the fine synchronization process is a course synchronization



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position. This coarse synchronization position may be determined using the above discussed method, or using any other suitable method. The components which are identical to those of Figure 7A are similarly numbered and in an actual implementation would be shared if the common synchronizers of Figure 7A are to be used. The functionality of Figure 7B is replicated for each of the one or more receive antenna.

A fine synchronization process is performed for each of one or more receive antennas, and then an overall synchronization position is taken based on a combination of the fine synchronization positions. By way of overview, once the coarse synchronizers have determined the coarse synchronization position(s)  $\mu_{\text{coarse}}$ , each fine synchronizer performs an FFT on the signal samples on either side of the coarse synchronization position, to generate frequency domain components over the frequency band of OFDM sub-carriers. Each fine synchronizer searches the frequency domain components in order to locate the precise location of the FFT window. The precise location of the FFT window is required in order to perform OFDM demodulation in the frequency domain. The fine synchronizer locates the precise location of the FFT window by performing correlation measurements between the known PN codes ( $\text{PN}_{\text{sync}}^{(1)}$  &  $\text{PN}_{\text{sync}}^{(2)}$ ) and the frequency components within a searching window defined with respect to the coarse synchronization position  $\mu_{\text{coarse}}$ . The correlation measurements performed by each fine synchronizer are performed in the frequency domain, and one set of correlation measurements is performed for each known PN code ( $\text{PN}_{\text{sync}}^{(1)}$  &  $\text{PN}_{\text{sync}}^{(2)}$ ), that is, for each transmitting antenna 21 and 23 (or for how many of the one or more transmit antenna there are).

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Each fine synchronizer selects  $N_{\text{symbol}}$  signal samples starting at an initial signal sample within the searching window, where  $N_{\text{symbol}}$  is the number of signal samples in an OFDM symbol. For each transmitting antenna, each fine synchronizer determines a correlation measurement between the frequency domain signal samples and the PN code corresponding to the transmitting antenna.

More specifically, fine synchronization searching is performed near  $n_{\text{coarse}}$ . Supposing that the searching window is  $2N+1$ , the searching range is from  $(n_{\text{coarse}} - N)$  to  $(n_{\text{coarse}} + N)$ . Let  $n_{\text{start}}(i) = n_{\text{coarse}} + N - i$  represent the sample index within the fine searching window, where  $i = 0, \dots, 2N$ . The fine synchronization starts from  $i = 0$ . Then  $N_{\text{symbol}}$  samples are taken starting from  $n_{\text{start}}(0)$ , the prefix is removed and FFT is performed. The received OFDM symbol in frequency domain can be written as:

$$R(i, l) = \text{FFT}(x(n(i), l)), n(i) = [n_{\text{start}}(i) + N_{\text{prefix}}, n_{\text{start}}(i) + N_{\text{symbol}} - 1]; i = 1, \dots, N_{\text{FFT}}$$

where  $N_{\text{prefix}}$  is the number of prefix samples and  $N_{\text{FFT}}$  is the FFT size.

From  $R$ , the complex data  $R^{(j, k)}_{\text{SYNC}}$  carried by the common synchronization channel of different transmitters is extracted, since common synchronization channels are divided between different transmitters in MIMO OFDM system. More generally, the complex the data corresponding to a transmitted training sequence is extracted. The correlation between  $R^{(j, k)}_{\text{SYNC}}$  and  $PN^{(i)}_{\text{SYNC}}$  is:

$$\gamma_f^{(j, k)}(i) = \sum_{m=0}^{N_{\text{sync}}-1} R^{(j, k)}_{\text{SYNC}}(m, i) \cdot PN^{(i)*}_{\text{SYNC}}(m), i = 0, \dots, 2N$$

where  $j = 1, 2, \dots, N_{\text{TX}}$  indicates transmitter,  $k = 1, 2, \dots, N_{\text{RX}}$  indicates receiver,  $PN^{(i)}_{\text{SYNC}}$  is the common SYNC PN code for  $j^{\text{th}}$  transmitter and  $N_{\text{sync}}$  is the size of common PN code.

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Then the starting point index  $n_{start}$  is shifted by one ( $n_{start}(1) = n_{start}(0) - 1$ ), and another  $N_{symbol}$  samples are processed as described above. In order to get the new frequency domain data  $X^{(j,k)}_{sync}(m, 1)$ , we need to perform FFT again. An iterative method can be used for this purpose to reduce the computational complexity:

$$R(l, i) = R(l, i-1) \cdot e^{j2\pi(i-1)/NFFT} + X(n_{start}(i) + N_{symbol} - 1) - X(n_{start}(i-1) + N_{symbol} - 1)$$

where NFFT is the FFT size. Extracting  $R^{(j,k)}_{sync}(m, 1)$ , the new correlation is calculated. The above procedure is continued until  $n_{start}$  moves out of the fine searching window.

For each

$$n_{fine} = \arg \max \left( \prod_{j=1}^{N_r} \prod_{k=1}^{N_s} | \gamma^{(j,k)}(i) | \right) \quad \begin{array}{l} \text{receive antenna, a} \\ \text{15} \quad \text{respective fine} \end{array}$$

synchronization position can be found by finding  $n_{start}(i)$  corresponding to the maximum of the products of the correlation results from different antennas over  $i = 0, \dots, 2N$ . In mathematical terms, for the kth receive antenna, a respective fine synchronization position can be selected according to:

$$n_{fine}(k) = \arg \max \left( \prod_{j=1}^{N_r} | \gamma^{(j,k)}(i) | \right)$$

To reduce the possibility of false alarm, a criterion may be set. For example, the fine synchronization may be considered to be achieved if the following condition is satisfied,

$$\max \left( \prod_{j=1}^{N_r} | \gamma^{(j,j)}(i) | \right) > N_{threshold} \cdot \frac{1}{2N} \sum_{k=1}^{N_s} \prod_{j=1}^{N_r} | \gamma^{(j,k)}(i) |$$

where  $N_{threshold}$  is a factor determined by the pre-set fine searching window size. Preferably, an overall fine

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synchronization position is then taken to be the earliest of the fine synchronization positions determined for the different receive antennas.

The fine synchronization process for one receive antenna is illustrated diagrammatically in Figure 7B. At the output of the first receiver 736, blocks D0 738 through D2N 742 represent alignment of the FFT blocks 744,...,748 for the various candidate fine synchronization positions (2N+1 in all). The FFT blocks 744,...,748 compute an FFT on each respective set of samples. Each FFT output is fed to a correlator block for each transmit antenna. If there are two transmit antennae, then there would be two such correlator blocks per FFT output. For example FFT 744 has an output fed to a first correlator block 745 for the first transmit antenna, and fed to a second correlator block 755 for a second transmit antenna. It is noted that if the spacing of the sub-carriers used to transmit the training sequence (the common synchronization sequence or pilot channel sequence in the above examples), a full FFT does not need to be completed in order to recover the training sequence components. The correlator block 745 for the first antenna multiplies with multiplier 747 the recovered training sequence symbol locations of the FFT output by the known training sequence for the first transmit antenna and these multiplications are added in summer 751. This same computation done in correlator 755 for the known training sequence of the second transmit antenna and the training sequence locations for the second transmit antenna. This is done at the first receiver for all of the different possible shifts for each transmit antenna. The correlation results across different transmit antennas for each possible shift are multiplied together in multipliers 753. The shift which results in the maximum of these multiplications is selected to be the fine synchronization position for the particular

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receiver. The same process is followed for any other receive antennas, and the overall fine synchronization position is preferably taken as the earliest of the fine synchronization positions thus computed.

5       The timing synchronization can be tracked every frame in case that the synchronization position drifts or losses. For example, in systems employing the previously described preamble, each time a preamble arrives at the receiver the 2-step process of synchronization is repeated,  
10 using the same method for coarse synchronization and fine synchronization. In this case, a smaller searching window  $N$  may be used based on the assumption that the drift of the synchronization position should be around the vicinity of the current location. After acquisition, the dedicated  
15 pilot channel code assigned to modulate dedicated pilot channels for different BTS can be used in the correlator, or the common synchronization sequence can be used, or some other training sequence.

      An embodiment of the invention has been described  
20 with respect to an MIMO-OFDM transmitter having more than one transmitting antenna. The method of performing synchronization at the OFDM receiver may also be applied to a signal received from an OFDM transmitter having only one transmitting antenna, as long as a known training sequence  
25 is inserted in the frame by the OFDM transmitter.

      Lastly, in the embodiment of the invention described thus far there has only been one transmitter having multiple antennae and one receiver having multiple antennae. In what follows, the concepts of the invention  
30 will be broadened to encompass the multi-cellular environment having many MIMO-OFDM transmitters and many MIMO-OFDM receivers.

Access in a Multi-Cellular Environment

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System access in a multi-cellular environment introduces the new problem of cell selection, as there will be many transmitters transmitting the same common pilot symbols. In another embodiment of the invention, the  
5 previously introduced transmit header is used by receivers to perform systems access and cell selection.

During initial acquisition, the UE starts by performing coarse synchronization. This may be done using the previously described methods, or some other method.  
10 After one frame duration, the coarse synchronization position is determined. Fine synchronization search algorithm is performed afterwards based on the common synchronization channel. Because the data carried by the common synchronization channel are the same for all BTS,  
15 several fingers (peaks) can be observed in a multi-cell environment and multi-path fading propagation channels. These fingers usually correspond to different BTS and/or different paths. Referring to Figure 8, shown is an example of fine synchronization (to the common synchronization  
20 channel) raw output computed in a multi-cellular environment as a function of sample index. In the present example there are five significant fingers 400, 402, 404, 406, and 408. The M strongest fingers are chosen and the corresponding positions are located, where M is a system design parameter.  
25 These positions are used as candidates for final synchronization and also as the positions upon which BTS identifications are made.

The results of Figure 8 do not allow BTS identification because BTS transmit the same common  
30 synchronization sequences. At each candidate synchronization position, the correlations of the received dedicated pilot channel sub-carriers and all possible complex sequences (dedicated pilot PN sequences) assigned to

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different BTS are calculated to scan for the presence of all the possible adjacent BTSs. In the multiple transmit antenna case, preferably this correlation is done on the basis of the combined dedicated pilot PN sequences of the multiple antennas over all of the dedicated pilot sub-carriers to generate a single correlation result for each index. Figure 9 shows an example of the relation between the BTS scanning results and the checking points (candidate synchronization positions). The BTS identification is realized by detecting the PN code corresponding to the maximum correlation value at each candidate synchronization position. C/I can be computed based on all correlation results at each checking position. At the initial acquisition stage, the cell selection is determined by selecting the BTS with the largest C/I ratio. In the present example two BTS are identified, a first BTS BTS1 and a second BTS BTS2. With multiple-antenna receiver diversity, the final decision of the cell selection should be based on the comparison of the highest C/I obtained by different receiver antennae at a receiver.

To obtain the final synchronization position, fine synchronization is performed again, but by using the dedicated pilot channel and the dedicated complex sequence found through the BTS identification. A smaller searching window around the fine synchronization position is used. The final synchronization results from different receivers are compared. The position corresponding to the earliest sample in time is used as the final synchronization position. This step is to reduce the possibility that a weak path (multi-path) is selected because of the short-term fading. To reduce the false alarm probability, a threshold is set. This threshold can be the ratio of the finger strength with respect to the final synchronization position and the average of the correlation within the search window.

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In the normal data processing stage, the fine synchronization and the BTS identification steps are repeated every frame when a new preamble is received, but a small set of the candidate PN codes is applied in the BTS scan. After BTS identification, a BTS candidates list can be generated through searching strong interferences. This list is updated periodically, for example every 10 ms, and provides information for BTS switch and even soft handoff. Certain criteria can be set in order to trigger the BTS switch and soft handoff. To average the impact from the fading, the decision for BTS switching and the soft handoff may be based on observation during a certain period. The criteria can be the comparison of the maximum correlation values representing C and the strongest I. It should be noted that after the cell switch and the soft handoff, the synchronization may also be adjusted by the final step in the initial access. The overall cell selection and re-selection method is shown in Figure 10.

In the first step 600, coarse synchronization is performed for example based on the preamble header in the time domain. This involves finding a coarse boundary between each frame by looking for two identical symbols. Correlating samples over adjacent symbol durations until a peak is found does this. Step 600 relies on a preamble to a frame beginning with two adjacent identical symbols.

Next during step 602, at the coarse synchronization peaks, an FFT is computed, and a switch to the processing of the common synchronization channel in the frequency domain is made. A search window is centered on sync position +/- a certain number of samples. The M strongest correlation peaks are selected, as per 604. At this time, it is not known which BTS each peak is associated with. BTS identification has not yet been determined.



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Then at step 606, for each correlation peak, the FFT is again computed and the correlations associated with the fine synchronization procedure are computed using the dedicated pilot channels - these containing a base station specific complex sequences. This is immediately followed by step 608 where the correlation with the BTS identification complex sequences is made in order to allow an identification of the associated base stations. At step 610, a C/I ratio is computed for each BTS thus identified. 5  
10 BTS selection and BTS switching is performed on the basis of these C/I ratios in step 612. As indicated above, BTS switching is performed on the basis of these C/I ratios averaged over some time interval.

Finally, for access, the FFT is computed and fine 15  
synchronization is applied to the dedicated pilot channel of the BTS with the largest C/I ratio as per step 614.

BTS initial synchronization performed on the common synchronization channel. A BTS specific sequence is embedded in the frequency domain and BTS identification 20  
processing is performed in the frequency domain allowing the elimination of MIMO-OFDM inter-channel interference. BTS power estimation is performed based on the pilot channel for each MIMO-OFDM BTS. BTS selection is performed based on C/I ratio measurements.

25 The result is improvement of the synchronization and identification of the serving BTS in a severe multi-path channel and high interference environment by joint BTS synchronization and cell selection. Channel estimation may be performed on a combined common synchronization channel 30  
and dedicated pilot channel. Criteria are provided for cell switching and soft handoff by C/I estimation.

In the above example, the access has been performed based on the synchronization channel and pilot

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channel embedded in the previously discussed preamble. More generally, the access can be performed with such channels embedded in any suitable manner within an OFDM symbol stream.

5       What has been described is merely illustrative of the application of the principles of the invention. Other arrangements and methods can be implemented by those skilled in the art without departing from the spirit and scope of the present invention.

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We claim:

1. A MIMO-OFDM transmitter adapted to transmit a header symbol format in which sub-carriers of a header OFDM symbol are divided into a non-contiguous set of sub-carriers  
5 for each of a plurality of antennas, with each antenna transmitting the header OFDM symbol only on the respective set of sub-carriers.
2. A transmitter according to claim 1 wherein there are N antennas and a different set of sub-carriers separated  
10 by N sub-carriers is assigned to each of the plurality of antennas.
3. A transmitter according to claim 1 wherein the header symbols contain a multiplexed dedicated pilot channel on dedicated pilot channel sub-carriers and common  
15 synchronization channel on common synchronization channel sub-carriers for each of the plurality of antennas.
4. A transmitter according to claim 3 wherein the header OFDM symbols further contain multiplexed broadcasting sub-carriers for each of the plurality of antennas.
- 20 5. A transmitter according to claim 1, adapted to transmit a preamble having a prefix, followed by two identical OFDM symbols having said header OFDM symbol format.
6. A transmitter according to claim 5 wherein the  
25 prefix is a cyclic extension of the two identical OFDM symbols.
7. A transmitter according to claim 3 wherein the pilot channel sub-carriers have a BTS specific mapped complex sequence allowing efficient BTS identification.
- 30 8. A transmitter according to any one of claims 3 wherein the common synchronization channel is designed for fast and accurate initial acquisition.

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9. A transmitter according to claim 3 wherein the common synchronization channel is used for course synchronization and fine synchronization and the pilot channel is used for fine synchronization.
- 5 10. A transmitter according to claim 3 wherein the common synchronization channel is used to transmit a complex sequence which is different for each transmit antenna of one transmitter, but which is common for respective transmit antennas of different transmitters within a communications
- 10 network.
11. A transmitter according to claim 1 adapted to transmit OFDM frames beginning with said preamble, and having scattered pilots throughout a remainder of the OFDM symbols in each OFDM frame.
- 15 12. A transmitter according to claim 1 wherein during the preamble, for each of N transmit antennas, dedicated pilot channel sub-carriers are transmitted and common synchronization channel sub-carriers are transmitted and broadcasting channel sub-carriers are transmitted.
- 20 13. A transmitter according to claim 3 wherein the sub-carriers of the preamble OFDM symbols are organized as a repeating sequence of {dedicated pilot channel for each of N transmit antennas, common synchronization channel sub-carrier for each of N transmit antennas} arranged in a
- 25 predetermined order.
14. A transmitter according to claim 4 wherein the sub-carriers of the preamble OFDM symbols are organized as a repeating sequence of {at least one dedicated pilot channel sub-carrier for each of N transmit antennas, at least one
- 30 common synchronization channel sub-carrier for each of N transmit antennas, at least one broadcast channel sub-carrier} arranged in a predetermined order.

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15. A MIMO-OFDM receiver adapted to receive a header symbol format in which sub-carriers of a header OFDM symbol are divided into a non-contiguous set of sub-carriers for each of a plurality of antennas, with each antenna  
5 transmitting the header OFDM symbol only on the respective set of sub-carriers.
16. A receiver according to claim 15 adapted to receive from N transmit antennas with a different set of sub-carriers separated by N sub-carriers assigned to each of  
10 the plurality of transmit antennas.
17. A receiver according to claim 15 wherein the header OFDM symbols contain multiplexed dedicated pilot channel sub-carriers and common synchronization channel sub-carriers for each of the plurality of transmit antennas.
- 15 18. A receiver according to claim 17 wherein the header OFDM symbols further contain multiplexed broadcasting carriers for each of the plurality of antennas.
19. A receiver according to claim 15 adapted to receive a preamble having a prefix, followed by two  
20 identical OFDM symbols having said header OFDM symbol format.
20. A receiver according to claim 15 wherein the dedicated pilot channel has a BTS specific mapped complex sequence, the receiver being adapted to perform BTS  
25 identification on the basis of the dedicated pilot channel.
21. A receiver according to claim 19 wherein the dedicated pilot channel have a BTS specific mapped complex sequence, the receiver being adapted to perform BTS identification on the basis of the dedicated pilot channel.
- 30 22. A receiver according to claim 21 wherein the header OFDM symbols contain multiplexed dedicated pilot channel sub-carriers and common synchronization channel sub-

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carriers for each of the plurality of transmit antennas, the receiver being further adapted to perform course synchronization on the common synchronization channel by looking for a correlation peak between consecutive OFDM symbols which are identical.

23. A receiver according to claim 22 further adapted to perform fine synchronization on the basis of the common synchronization channel sub-carriers and/or the dedicated pilot channel sub-carriers.
24. A transmitter adapted to transmit a packet data frame structure comprising:
- a superframe having a length corresponding to a synchronization period of a network;
  - the superframe containing a plurality of radio frames;
  - each radio frame containing a plurality of TPS (transmission parameter signalling) frames corresponding to an adaptive coding and modulation period;
  - each TPS frame containing a plurality of slots corresponding to an air interface slot size;
  - each slot containing a plurality of OFDM symbols, with the first two symbols of the first slot of the first TPS frame of each OFDM frame being used as header OFDM symbols.
25. A transmitter according to claim 24 wherein the header OFDM symbols have a header OFDM symbol format in which sub-carriers of a header OFDM symbol are divided into a non-contiguous set of sub-carriers for each of a plurality of antennas, with each antenna transmitting the header OFDM symbol only on the respective set of sub-carriers.

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26. A transmitter according to claim 24 wherein the header OFDM symbols contain multiplexed pilot channel sub-carriers and common synchronization channel sub-carriers for each of the plurality of antennas.
- 5 27. A transmitter according to claim 24 wherein the header OFDM symbols further contain multiplexed broadcasting channel sub-carriers for each of the plurality of antennas.
28. A transmitter according to claim 24 adapted to transmit in a plurality of different modes by transmitting a  
10 different number of OFDM symbols per slot with an unchanged slot duration and with no change to the frame structure above the slot.
29. A transmitter according to claim 28 wherein modes with an increased number of OFDM symbols per slot are  
15 realized by shortening OFDM symbol duration, and shortening FFT size, but not changing sampling frequency.
30. A transmitter according to claim 24 adapted to transmit to a respective set of users for each TPS frame and to signal for each TPS frame which users should demodulate  
20 the entire TPS frame.
31. A receiver adapted to receive and process OFDM frames transmitted by the transmitter of claim 24.
32. A method of performing synchronization at an OFDM receiver comprising:
- 25 at each of at least one receive antenna, sampling a received signal to produce a respective set of time domain samples;
- determining at least one course synchronization position;
- 30 at each of the at least one receive antenna:

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- a) for each of a plurality of candidate fine synchronization positions about one of said at least one course synchronization position:
- i) for each receive antenna
- 5 positioning an FFT window to the candidate fine synchronization position and converting by FFT the time domain samples into a respective set of frequency domain components;
- ii) for each said at least one
- 10 transmit antenna, extracting a respective received training sequence corresponding to the transmit antenna from the sets of frequency domain components;
- iii) for each transmit antenna, calculating a correlation between each respective received
- 15 training sequence and a respective known transmit training sequence;
- iv) combining the correlations for the at least one transmit antennas to produce an overall correlation result for each candidate synchronization
- 20 position;
- b) determining a fine synchronization position from the plurality of correlation values;
- combining the fine synchronization positions from the at least one receive antenna in an overall fine
- 25 synchronization position.
33. A method according to claim 32 wherein a course synchronization position is determined for each receive antenna and used for determining the respective fine synchronization position.
- 30 34. A method according to claim 32 a course synchronization position is determined for each receive



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antenna and an earliest of the positions is used determining the fine synchronization positions for all receive antennas.

35. A method according to claim 33 wherein the course synchronization position is determined in the time domain  
5 for at least one receive antenna by looking for a correlation peak between the time domain samples over two OFDM symbol durations.

36. A method according to claim 32 applied at an OFDM receiver having at least two antennas, combining the fine  
10 synchronization positions from the at least one receive antenna in an overall fine synchronization position comprises selecting an earliest of the fine synchronization positions.

37. A method according to claim 32 wherein:  
15 sampling a received signal to produce a set of time domain samples is done for at least three OFDM symbol durations;

determining at least one course synchronization position comprises performing a course synchronization in  
20 the time domain by looking for a correlation peak between the time domain samples received over two OFDM symbol durations to identify a course synchronization position by:

a) calculating a plurality of correlation values, each correlation value being a correlation  
25 calculated between a first set of time domain samples received during a first period having one OFDM symbol duration and a second set of time domain samples received during a second period immediately following the first period and having OFDM symbol duration, for each of a  
30 plurality of starting times for said first period;

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b) identifying the course synchronization position to be a maximum in said plurality of correlation values.

38. A method according to claim 32 wherein:

5 combining the correlations for the at least one transmit antennas to produce an overall correlation result for each candidate synchronization position comprises multiplying together the correlations for the at least one transmit antenna for each candidate synchronization  
10 position.

39. A method according to claim 32 applied to a single transmit antenna single receive antenna system.

40. A method according to claim 32 wherein the training sequence is received on common synchronization  
15 channel sub-carriers.

41. A method according to claim 32 wherein the training sequence is received during an OFDM frame preamble.

42. A method according to claim 32 wherein the training sequence is received on dedicated pilot channel  
20 sub-carriers.

43. A method according to claim 42 wherein the training sequence is received during an OFDM frame preamble.

44. An OFDM receiver comprising:

at least one receive antenna;

25 for each said at least one receive antenna, receive circuitry adapted to sample a received signal to produce a respective set of time domain samples;

a course synchronizer adapted to determine at least one course synchronization position;

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a fine synchronizer comprising at least one FFT, at least one correlator and at least one combiner, adapted to, at each of the at least one receive antenna:

- a) for each of a plurality of candidate
  - 5 fine synchronization positions about one of said at least one course synchronization position:
    - i) for each receive antenna
      - position an FFT window to the candidate fine synchronization position and convert by FFT the time domain samples into a
        - 10 respective set of frequency domain components;
        - ii) for each said at least one transmit antenna, extract a respective received training sequence corresponding to the transmit antenna from the sets of frequency domain components;
        - 15 iii) for each transmit antenna, calculate a correlation between each respective received training sequence and a respective known transmit training sequence;
        - iv) combine the correlations for
          - 20 the at least one transmit antennas to produce an overall correlation result for each candidate synchronization position;
      - b) determine a fine synchronization position from the plurality of correlation values;
    - 25 the receiver being further adapted to combine the fine synchronization positions from the at least one receive antenna in an overall fine synchronization position.
  45. A receiver according to claim 44 having at least two receive antennas, adapted to combine the fine
    - 30 synchronization positions from the at least one receive antenna in an overall fine synchronization position by selecting an earliest of the fine synchronization positions.

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46. A receiver according to claim 44 adapted to combine the correlations for the at least one transmit antennas to produce an overall correlation result for each candidate synchronization position by multiplying together  
 5 the correlations for the at least one transmit antenna for each candidate synchronization position.

47. A receiver according to claim 44 adapted to receive the training sequence on common synchronization channel sub-carriers.

10 48. A receiver according to claim 44 adapted to receive the training sequence on dedicated pilot channel sub-carriers.

49. A method of performing fine synchronization comprising:

15 at each at least one receive antenna receiving OFDM symbols containing a respective received frequency domain training sequence for each of at least one transmit antenna;

performing fine synchronization in the frequency  
 20 domain by looking for maximum correlations between known frequency domain training sequences and the received frequency domain training sequences.

50. A method of transmitting signals enabling fine synchronization comprising:

25 from each of at least one transmit antenna, transmitting OFDM symbols containing a respective frequency domain training sequence.

51. A method according to claim 50 wherein a different frequency domain training sequence is transmitted by each  
 30 transmit antenna, but the same frequency domain training sequence is transmitted by corresponding antenna of other transmitters.

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52. A method of performing cell selection at an OFDM receiver comprising:

at each of at least one receive antenna, sampling  
a received signal to produce a respective set of time domain  
5 samples;

determining at least one course synchronization  
position;

at each of the at least one receive antenna:

a) performing a frequency domain  
10 correlation between at least one received common  
synchronization sequence extracted from common  
synchronization channel sub-carriers in the received signal  
and a corresponding common synchronization sequence of a  
respective plurality of transmit antennas to identify a  
15 plurality of candidate correlation peaks;

b) selecting the M strongest correlation  
peaks for further processing;

c) at each correlation peak, reconvert  
time domain samples into frequency domain components and  
20 processing pilot channel sub-carriers, these containing  
transmitter specific information, to identify a transmitter  
associated with each correlation peak;

d) determining a C/I or similar value for  
each transmitter thus identified;

25 selecting the transmitter having the largest C/I  
determined for any of the at least one receive antenna.

53. A method according to claim 52 wherein performing  
a frequency domain correlation between at least one received  
common synchronization sequence extracted from common  
30 synchronization channel sub-carriers in the received signal  
and a corresponding common synchronization sequence of a

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respective plurality of transmit antennas to identify a plurality of candidate correlation peaks comprises:

- a) for each of a plurality of candidate fine synchronization positions about one of said at least one course synchronization position:
  - i) for each receive antenna positioning an FFT window to the candidate fine synchronization position and converting by FFT the time domain samples into a respective set of frequency domain components;
    - ii) for each of at least one common synchronization sequence, each common synchronization sequence having been transmitted by a transmit antenna of each of at least one transmitter, extracting a respective received training sequence corresponding to the transmit antennas from the sets of frequency domain components;
      - iii) for each of the at least one common synchronization sequence, calculating a correlation between each respective received common synchronization sequence and a respective known common synchronization sequence;
        - iv) combining the correlations to produce an overall correlation result for each candidate synchronization position;
    - b) determining at least one peak in the correlations, each said at least one peak being local maxima in the correlations.

54. A method according to claim 53 further comprising: reconverting time domain samples into frequency domain components based on the fine synchronization position of the selected transmitter and performing a further fine

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synchronization based on a dedicated pilot channel for that transmitter.

55. A method according to claim 54 applied to a MIMO-OFDM frame format having a header symbol format in which  
5 subcarriers of a header symbol are divided into a non-contiguous set of subcarriers for each of a plurality of antennas, with each antenna transmitting header symbols only on the respective set of sub-carriers, and wherein the header symbols contain multiplexed pilot channel sub-carriers and common synchronization channel sub-carriers for  
10 each of the plurality of antennas, the frame beginning with two identical header OFDM symbols during which contents of the pilot channel sub-carriers are repeated and contents of the synchronization channel sub-carriers are repeated, the  
15 common synchronization channel sub-carriers carrying a complex sequence which is different for respective antenna of one base station and being common across multiple base stations, and contents of the dedicated pilot channel sub-carriers being at least locally unique to a particular base  
20 station.

56. A method according to claim 52 further comprising:  
for transmitter switching, averaging the C/I or similar value over a time interval for each transmitter thus identified, and at the end of the time interval instigating  
25 a transmitter switch to the transmitter with the largest average C/I or similar value if different from a currently selected transmitter.

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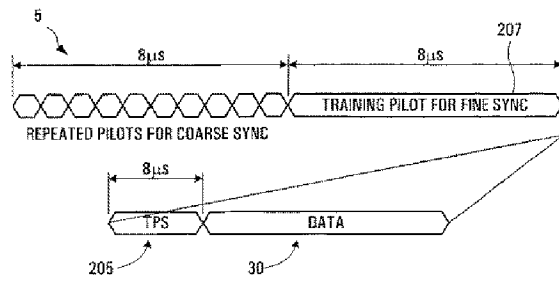


FIG. 1A

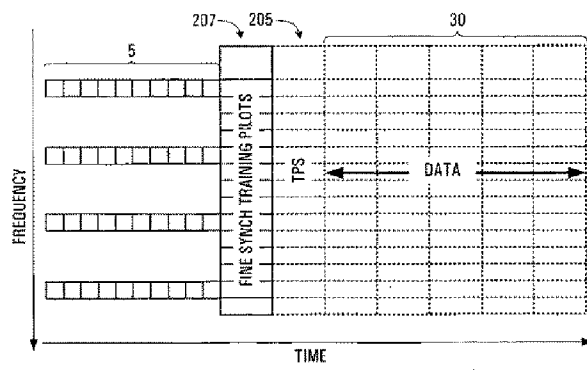


FIG. 1B



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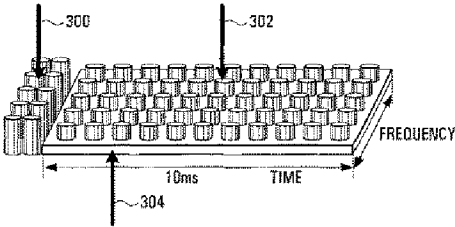


FIG. 2A

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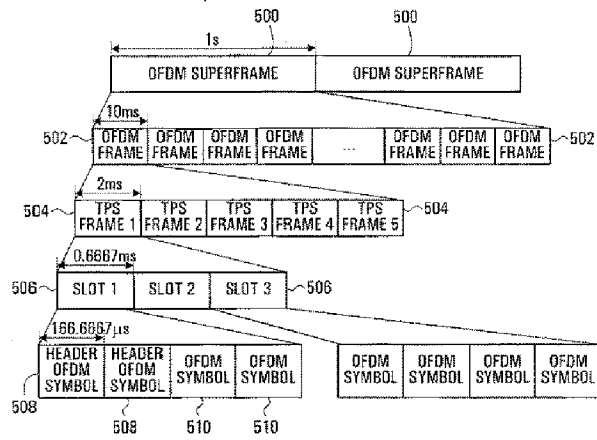


FIG. 2B

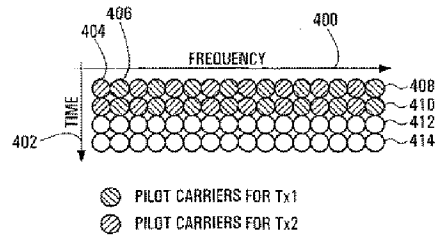


FIG. 3

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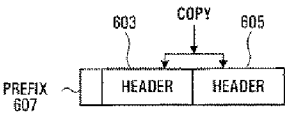


FIG. 4

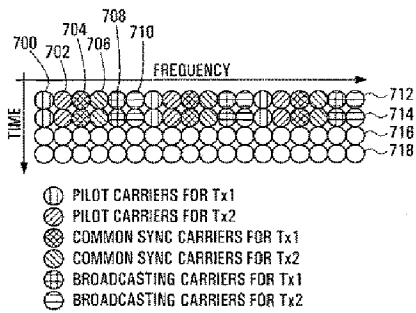
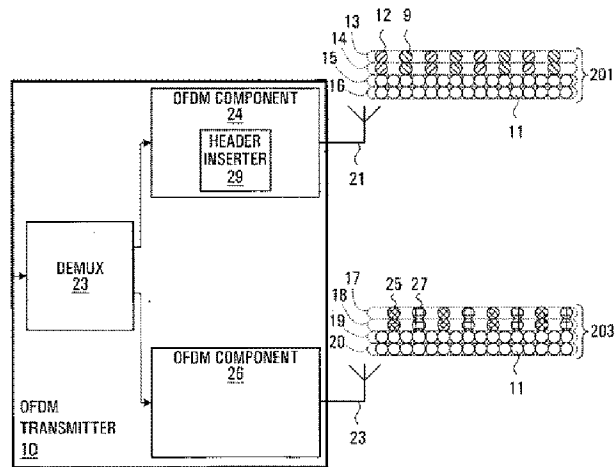


FIG. 5

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- ⊗ -DEDICATED PILOT CHANNEL FOR ANT#1
- ⊗ -DEDICATED PILOT CHANNEL FOR ANT#2
- ⊗ -COMMON SYNCHRONIZATION CHANNEL FOR ANT#1
- ⊗ -COMMON SYNCHRONIZATION CHANNEL FOR ANT#2

FIG. 6

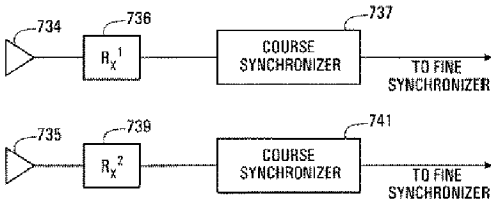
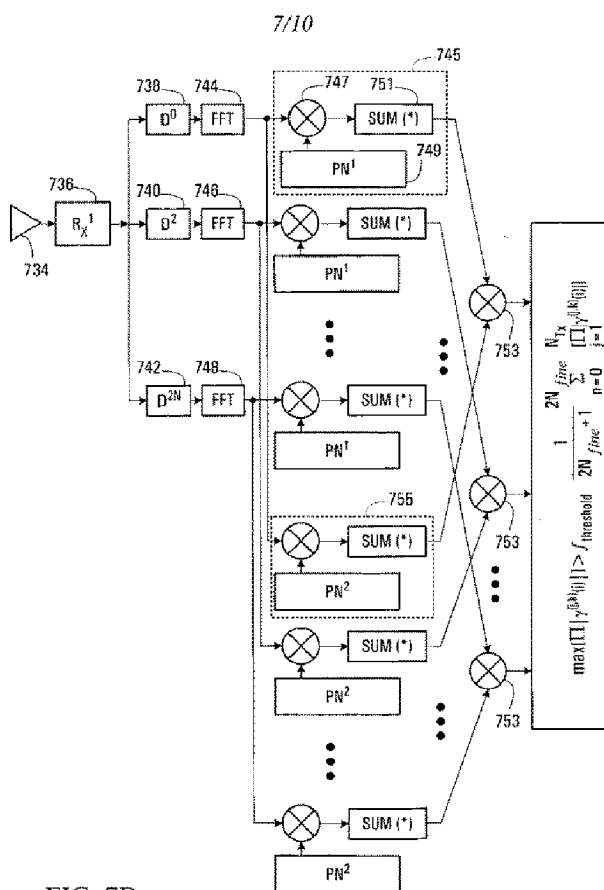


FIG. 7A

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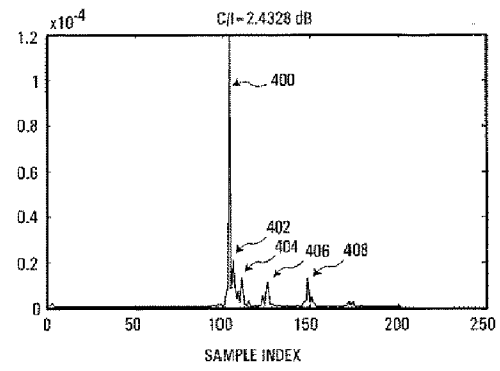


FIG. 8

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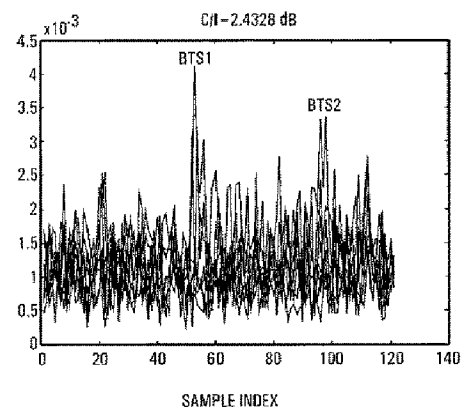


FIG. 9



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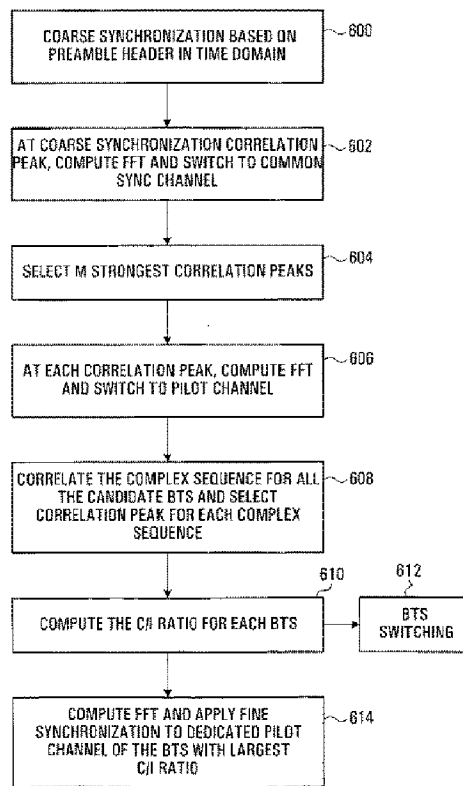


FIG. 10

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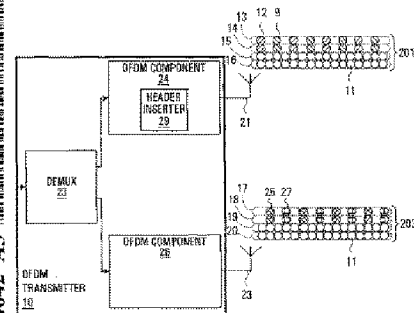
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10038,915 8 January 2002 (08.01.2002) US(71) Applicant: **NORTEL NETWORKS LIMITED**  
[CA/CA]. 2351 Boulevard Alfred-Nobel, St. Laurent, Quebec H4S 2A9 (CA)(72) Inventors: **MA, Jiaqin**, 3 Bon Echo Cres., Knares,  
Ontario K2M 2W5 (CA); **JIA, Ming**, 609-230 Crofton  
Avenue, Ottawa, Ontario K2B 5P3 (CA); **ZHU, Peiyang**,  
16 Pebble Creek Cres., Kanata, Ontario K2M 2L4 (CA);  
**TONG, Wen**, 12 Whitestone Drive, Ottawa, Ontario K2C  
4A7 (CA).(74) Agents: **BRETTE, R., Allan et al.**, Smart & Biggar, 900-55  
Metcalfe Street, E.O. Box 2969, Station D, Ottawa, Ontario  
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(Continued on next page)

(54) Title: **SYNCHRONISATION IN MULTICARRIER CDMA SYSTEMS**

(57) Abstract: A method and apparatus are provided for performing acquisition, synchronization and cell selection within an MIMO-OFDM communication system. A coarse synchronization is performed to determine a searching window. A fine synchronization is then performed by measuring correlations between subsets of signal samples, whose first signal sample lies within the searching window, and known values. The correlations are performed in the frequency domain of the received signal. In a multiple-output OFDM system, each antenna of the OFDM transmitter has a unique known value. The known value is transmitted as pairs of consecutive pilot symbols, each pair of pilot symbols being transmitted at the same subset of sub-carrier frequencies within the OFDM frame.

- ① DEDICATED PILOT CHANNEL FOR ANT#1
- ② DEDICATED PILOT CHANNEL FOR ANT#2
- ③ COMMON SYNCHRONIZATION CHANNEL FOR ANT#1
- ④ COMMON SYNCHRONIZATION CHANNEL FOR ANT#2

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*[Continued on next page]*

**(57) Abstract:** A method and apparatus are provided for performing acquisition, synchronization and cell selection within an MMIO-OFDM communication system. A coarse synchronization is performed to determine a searching window. A fine synchronization is then performed by measuring correlations between subsets of signal samples, whose first signal sample lies within the searching window, and known values. The correlations are performed in the frequency domain of the received signal. In a multiple-output OFDM system, each antenna of the OFDM transmitter has a unique known value. The known value is included in pairs of conjugate pilot symbols, each pair of pilot symbols being transmitted at the same subset of sub-carrier frequencies within the OFDM frame.

- ② DEDICATED PILOT CHANNEL FOR ANT#1
- ③ DEDICATED PILOT CHANNEL FOR ANT#2
- ④ COMMON SYNCHRONIZATION CHANNEL FOR ANT#1
- ⑤ COMMON SYNCHRONIZATION CHANNEL FOR ANT#2

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【手続補正書】

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【手続補正1】

【補正対象書類名】特許請求の範囲

【補正対象項目名】全文

【補正方法】変更

【補正の内容】

【特許請求の範囲】

【請求項1】

複数のアンテナのそれぞれにおいてヘッダOFDMシンボルの副搬送波が副搬送波の非連続なセットに分割されるというヘッダシンボルフォーマットを送信するようになっており、

各アンテナは、副搬送波の各セット上でのみ前記ヘッダOFDMシンボルを送信する、MIMO-OFDM送信機。

【請求項2】

N個のアンテナが存在し、N個の副搬送波によって分離された副搬送波の異なるセットが前記複数のアンテナのそれぞれに対して割り当てられる、請求項1に記載のMIMO-OFDM送信機。

【請求項3】

前記ヘッダシンボルは、前記複数のアンテナのそれぞれにおいて、専用パイロットチャネル副搬送波上に、多重化された専用パイロットチャネルを含むとともに、共通同期チャネル副搬送波上に、共通同期チャネルを含む、請求項1に記載のMIMO-OFDM送信機。

【請求項4】

前記ヘッダOFDMシンボルは、前記複数のアンテナのそれぞれにおいて、多重化されたブロードキャスト副搬送波を更に含む、請求項3に記載のMIMO-OFDM送信機。

【請求項5】

プレフィックスと、該プレフィックスの後に続き且つ前記ヘッダOFDMシンボルフォーマットを有する2つの同一のOFDMシンボルとを有するプリアンプルを送信するようになっている、請求項1に記載のMIMO-OFDM送信機。

【請求項6】

前記プレフィックスは、前記2つの同一のOFDMシンボルの巡回拡張子である、請求項5に記載のMIMO-OFDM送信機。

【請求項7】

前記専用パイロットチャネル副搬送波は、効率的なBTS識別を行なうことができるBTS固有のマッピングされた複合シーケンスを有する、請求項3に記載のMIMO-OFDM送信機。

【請求項8】

前記共通同期チャネルは、高速で且つ正確な初期取得を行なえるように設計されている、請求項3のいずれか一つに記載のMIMO-OFDM送信機。

【請求項9】

前記共通同期チャネルは、粗同期および微同期のために使用され、前記専用パイロットチャネルは、微同期のために使用される、請求項3に記載のMIMO-OFDM送信機。

【請求項10】

前記共通同期チャネルは、1つの送信機の送信アンテナ毎に異なるが通信ネットワーク内の様々な送信機の各送信アンテナに共通する複合シーケンスを送信するために使用される、請求項3に記載のMIMO-OFDM送信機。

【請求項11】

前記プリアンプルから始まるOFDMフレームを送信するようになっており、前記OFDM

Mフレームは、各OFDMフレーム内の残りのOFDMシンボルにわたって分散パイロットを有する、請求項5に記載のMIMO-OFDM送信機。

【請求項12】

前記プリアンプル中、N個の送信アンテナのそれぞれにおいて、専用パイロットチャネル副搬送波が送信され、共通同期チャネル副搬送波が送信され、ブロードキャストチャネル副搬送波が送信される、請求項5に記載のMIMO-OFDM送信機。

【請求項13】

前記プリアンプルのOFDMシンボルの副搬送波は、所定の順序で配置される {N個の送信アンテナのそれぞれにおける専用パイロットチャネル，N個の送信アンテナのそれぞれにおける共通同期チャネル副搬送波} から成る繰り返しシーケンスとして編成される、請求項5に記載のMIMO-OFDM送信機。

【請求項14】

前記プリアンプルのOFDMシンボルの副搬送波は、所定の順序で配置される {N個の送信アンテナのそれぞれにおける少なくとも1つの専用パイロットチャネル副搬送波，N個の送信アンテナのそれぞれにおける少なくとも1つの共通同期チャネル副搬送波，少なくとも1つのブロードキャストチャネル副搬送波} から成る繰り返しシーケンスとして編成される、請求項5に記載のMIMO-OFDM送信機。

【請求項15】

ヘッダOFDMシンボルの副搬送波が複数のアンテナのそれぞれにおいて副搬送波の非連続なセットに分割されるというヘッダシンボルフォーマットを受信するようになっており、

各アンテナは、副搬送波の各セット上でのみ前記ヘッダOFDMシンボルを送信する、MIMO-OFDM受信機。

【請求項16】

N個の送信アンテナから受信するようになっており、N個の副搬送波によって分離された副搬送波の異なるセットが複数の各送信アンテナに対して割り当てられる、請求項15に記載のMIMO-OFDM受信機。

【請求項17】

前記ヘッダOFDMシンボルは、前記複数の送信アンテナのそれぞれにおいて、多重化された専用パイロットチャネル副搬送波と共通同期チャネル副搬送波とを含む、請求項15に記載のMIMO-OFDM受信機。

【請求項18】

前記ヘッダOFDMシンボルは、前記複数のアンテナのそれぞれにおいて、多重化されたブロードキャスト副搬送波を更に含む、請求項17に記載のMIMO-OFDM受信機。

【請求項19】

プレフィックスと、該プレフィックスの後に続き且つ前記ヘッダOFDMシンボルフォーマットを有する2つの同一のOFDMシンボルとを有するプリアンプルを受信するようになっている、請求項15に記載のMIMO-OFDM受信機。

【請求項20】

前記専用パイロットチャネルは、BTS固有のマッピングされた複合シーケンスを有し、本MIMO-OFDM受信機は、該専用パイロットチャネルに基づいてBTS識別を行なうようになっている、請求項15に記載のMIMO-OFDM受信機。

【請求項21】

前記専用パイロットチャネルは、BTS固有のマッピングされた複合シーケンスを有し、本MIMO-OFDM受信機は、該専用パイロットチャネルに基づいてBTS識別を行なうようになっている、請求項19に記載のMIMO-OFDM受信機。

【請求項22】

前記ヘッダOFDMシンボルは、複数の送信アンテナのそれぞれにおいて、多重化された専用パイロットチャネル副搬送波と、共通同期チャネル副搬送波とを含み、本MIMO-OFDM受信機は更に、互いに同一の連続するOFDMシンボル間で相関ピークを探すこ

とにより、前記共通同期チャネルにおいて粗同期を行なうようになっている、請求項 2 1 に記載の MIMO-OFDM 受信機。

【請求項 2 3】

前記共通同期チャネル副搬送波及び／又は前記専用パイロットチャネル副搬送波に基づいて微同期を更に行なうようになっている、請求項 2 2 に記載の MIMO-OFDM 受信機。

【請求項 2 4】

パケットデータフレーム構造を送信するようになっている送信機であって、ネットワークの同期期間に対応する長さを有するスーパーフレームを備え、前記スーパーフレームは、複数の無線フレームを含み、各無線フレームは、適応コーディング及び変調期間に対応する複数の T P S（送信パラメータ信号）フレームを含み、各 T P S フレームは、エアーインタフェーススロットサイズに対応する複数のスロットを含み、各スロットは複数の OFDM シンボルを含み、各 OFDM フレームの最初の T P S フレームの最初のスロットの最初の 2 つのシンボルは、ヘッダ OFDM シンボルとして使用される、送信機。

【請求項 2 5】

前記ヘッダ OFDM シンボルは、該ヘッダ OFDM シンボルの副搬送波が複数のアンテナのそれぞれにおいて副搬送波の非連続なセットに分割されるというヘッダ OFDM シンボルフォーマットを有し、各アンテナは、副搬送波の対応するセット上でのみ前記ヘッダ OFDM シンボルを送信する、請求項 2 4 に記載の送信機。

【請求項 2 6】

前記ヘッダ OFDM シンボルは、複数のアンテナのそれぞれにおいて、多重化された専用パイロットチャネル副搬送波を含むとともに、共通同期チャネル副搬送波を含む、請求項 2 4 に記載の送信機。

【請求項 2 7】

前記ヘッダ OFDM シンボルは、前記複数のアンテナのそれぞれにおいて、多重化されたブロードキャストチャネル副搬送波を更を含む、請求項 2 4 に記載の送信機。

【請求項 2 8】

スロット持続時間が変わることなく且つスロットよりも上のフレーム構造を変えることなく 1 スロット毎に異なる数の OFDM シンボルを送信することにより、複数の異なるモードで送信するようになっている、請求項 2 4 に記載の送信機。

【請求項 2 9】

1 スロット当たりの OFDM シンボルの数が増大するモードは、サンプリング周波数を変えることなく OFDM シンボル持続時間および F F T サイズを短くすることにより実現される、請求項 2 8 に記載の送信機。

【請求項 3 0】

T P S フレーム毎にユーザの各組に対して送信するとともに、どのユーザが T P S フレーム全体を復調するべきかの信号を T P S フレーム毎に送信するようになっている、請求項 2 4 に記載の送信機。

【請求項 3 1】

請求項 2 4 に記載の送信機によって送信される OFDM フレームを受信して処理するようになっている受信機。

【請求項 3 2】

OFDM 受信機で同期を行なう方法であって、少なくとも 1 つの受信アンテナのそれぞれで、受信信号をサンプリングして、時間領域サンプルの各セットを形成し、少なくとも 1 つの粗同期位置を決定し、少なくとも 1 つの受信アンテナのそれぞれで、



a) 前記少なくとも1つの粗同期位置のうちの1つに関する複数の候補微同期位置のそれぞれにおいて、

i) 受信アンテナ毎に、候補微同期位置に対してFFTウィンドウを位置決めするとともに、FFTにより、時間領域サンプルを周波数領域成分の各セットに変換し、

ii) 前記少なくとも1つの送信アンテナそれぞれにおいて、周波数領域成分のセットから送信アンテナに対応する受信された各トレーニングシーケンスを抽出し、

iii) 送信アンテナ毎に、受信された各トレーニングシーケンスと周知の各送信トレーニングシーケンスとの間の相関を計算し、

iv) 少なくとも1つの送信アンテナにおいて相関を組み合わせて、候補同期位置毎に全体の相関結果を形成し、

b) 複数の相関値から微同期位置を決定し、

少なくとも1つの受信アンテナからの複数の微同期位置を組み合わせて全体の微同期位置とする、方法。

【請求項33】

粗同期位置は、受信アンテナ毎に決定されるとともに、各微同期位置を決定するために使用される、請求項32に記載の方法。

【請求項34】

粗同期位置が受信アンテナ毎に決定され、これらの位置のうちで最も早い位置が使用されて、全ての受信アンテナにおける微同期位置が決定される、請求項32に記載の方法。

【請求項35】

前記粗同期位置は、2つのOFDMシンボル持続時間にわたって時間領域サンプル間の相関ピークを探すことにより、少なくとも1つの受信アンテナにおいて時間領域で決定される、請求項33に記載の方法。

【請求項36】

少なくとも1つの受信アンテナからの複数の微同期位置を組み合わせて全体の微同期位置とすることは、前記微同期位置のうちの最も早い位置を選択することを含む、少なくとも2つのアンテナを有するOFDM受信機で適用される、請求項32に記載の方法。

【請求項37】

受信信号をサンプリングして時間領域サンプルの各セットを形成することは、少なくとも3つのOFDMシンボル持続時間において行なわれ、

少なくとも1つの粗同期位置を決定することは、2つのOFDMシンボル持続時間にわたって受けた前記時間領域サンプル間の相関ピークを探すことにより前記時間領域で粗同期を行ない、

a) 1つのOFDMシンボル持続時間を有する第1の期間中に受けた時間領域サンプルの第1のセットと、第1の期間の直ぐ次の第2の期間であってOFDMシンボル持続時間を有する第2の期間中に受けた時間領域サンプルの第2のセットとの間で計算された相関である複数の相関値のそれぞれを、前記第1の期間における複数の開始時間のそれぞれにおいて計算し、

b) 前記複数の相関値で最大となる粗同期位置を特定する、

ことにより、粗同期位置を特定することを含む、請求項32に記載の方法。

【請求項38】

少なくとも1つの送信アンテナにおいて相関を組み合わせて、候補同期位置毎に全体の相関結果を形成することは、候補同期位置毎に少なくとも1つの送信アンテナにおける相関を一緒に乗算することを含む、請求項32に記載の方法。

【請求項39】

送信アンテナが1つで且つ受信アンテナが1つのシステムに対して適用される、請求項32に記載の方法。

【請求項40】

前記トレーニングシーケンスは、共通同期チャネル副搬送波上で受信される、請求項32に記載の方法。

**【請求項 4 1】**

前記トレーニングシーケンスは、OFDMフレームプリアンブル中に受信される、請求項 3 2 に記載の方法。

**【請求項 4 2】**

前記トレーニングシーケンスは、専用パイロットチャネル副搬送波上で受信される、請求項 3 2 に記載の方法。

**【請求項 4 3】**

前記トレーニングシーケンスは、OFDMフレームプリアンブル中に受信される、請求項 4 2 に記載の方法。

**【請求項 4 4】**

少なくとも 1 つの受信アンテナと、  
前記少なくとも 1 つの受信アンテナ毎に設けられ、受信信号をサンプリングして、時間領域サンプルの各セットを形成するようになっている受信回路と、  
少なくとも 1 つの粗同期位置を決定するようになっている粗同期装置と、  
少なくとも 1 つのFFTと、少なくとも 1 つの相関器と、少なくとも 1 つのコンパイナとを備える微同期装置であって、少なくとも 1 つの受信アンテナのそれぞれで、  
a) 前記少なくとも 1 つの粗同期位置のうちの 1 つに関する複数の各候補微同期位置のそれぞれにおいて、  
i) 受信アンテナ毎に、前記候補微同期位置に対してFFTウィンドウを位置決めするとともに、FFTにより、前記時間領域サンプルを周波数領域成分の各セットに変換し、  
i i) 前記少なくとも 1 つの送信アンテナ毎に、周波数領域成分のセットから前記送信アンテナに対応する受信された各トレーニングシーケンスを抽出し、  
i i i) 送信アンテナ毎に、受信された各トレーニングシーケンスと周知の各送信トレーニングシーケンスとの間の相関を計算し、  
i v) 少なくとも 1 つの送信アンテナにおいて相関を組み合わせて、候補同期位置毎に全体の相関結果を形成し、  
b) 複数の相関値から微同期位置を決定する、  
ようになっている微同期装置と、  
を備え、  
少なくとも 1 つの受信アンテナからの前記微同期位置を組み合わせて全体の微同期位置とするようになっているOFDM受信機。

**【請求項 4 5】**

少なくとも 2 つの受信アンテナを有し、前記微同期位置のうちの最も早い位置を選択することにより、少なくとも 1 つの受信アンテナからの前記微同期位置を組み合わせて全体の微同期位置とするようになっている、請求項 4 4 に記載のOFDM受信機。

**【請求項 4 6】**

候補同期位置毎に少なくとも 1 つの送信アンテナにおける相関を一緒に乗算することにより、少なくとも 1 つの送信アンテナにおいて相関を組み合わせて、候補同期位置毎に全体の相関結果を形成するようになっている、請求項 4 4 に記載のOFDM受信機。

**【請求項 4 7】**

共通同期チャネル副搬送波上で前記トレーニングシーケンスを受信するようになっている、請求項 4 4 に記載のOFDM受信機。

**【請求項 4 8】**

専用パイロットチャネル副搬送波上で前記トレーニングシーケンスを受信するようになっている、請求項 4 4 に記載のOFDM受信機。

**【請求項 4 9】**

微同期を行なう方法であって、  
少なくとも 1 つの受信アンテナのそれぞれで、少なくとも 1 つの送信アンテナ毎に受けた各周波数領域トレーニングシーケンスを含むOFDMシンボルを受信し、  
周知の周波数領域トレーニングシーケンスと受信した周波数領域トレーニングシーケンス

との間で最大相関を見つけることにより、周波数領域で微同期を行なうことを含む方法。

【請求項 5 0】

微同期を可能にする信号を送信する方法であって、少なくとも 1 つの送信アンテナのそれぞれから、各周波数領域トレーニングシーケンスを含む OFDM シンボルを送信することを含む方法。

【請求項 5 1】

異なる周波数領域トレーニングシーケンスは各送信アンテナによって送信されるが、同じ周波数領域トレーニングシーケンスは、他の送信機の対応するアンテナによって送信される、請求項 5 0 に記載の方法。

【請求項 5 2】

OFDM 受信機でセル選択を行なう方法であって、少なくとも 1 つの送信アンテナのそれぞれで、受信信号をサンプリングして、時間領域サンプルの各セットを形成し、少なくとも 1 つの粗同期位置を決定し、少なくとも 1 つの受信アンテナのそれぞれで、  
a) 受信信号内の共通同期チャネル副搬送波から抽出された少なくとも 1 つの受信した共通同期シーケンスと、複数の送信アンテナのそれぞれに対応する共通同期シーケンスとの間で周波数領域相関を行なうことにより、複数の候補相関ピークを特定し、  
b) 更なる処理のために、M 個の最も強い相関ピークを選択し、  
c) 各相関ピークで、時間領域サンプルを周波数領域成分に再変換するとともに、送信機固有の情報を含むパイロットチャネル副搬送波を処理して、各相関ピークに関連付けられた送信機を特定し、  
d) そのように特定された各送信機において  $C/I$  または同様の値を決定し、任意の少なくとも 1 つの受信アンテナにおいて決定された  $C/I$  が最も大きい送信機を選択する、  
ことを含む方法。

【請求項 5 3】

受信信号内の共通同期チャネル副搬送波から抽出された少なくとも 1 つの受信した共通同期シーケンスと、複数の送信アンテナのそれぞれに対応する共通同期シーケンスとの間で周波数領域相関を行なうことにより、複数の候補相関ピークを特定することは、  
a) 前記少なくとも 1 つの粗同期位置のうちの 1 つに関する複数の各候補微同期位置のそれぞれにおいて、  
i) 受信アンテナ毎に、前記候補微同期位置に対して FFT ウィンドウを位置決めするとともに、FFT により、前記時間領域サンプルを周波数領域成分の各セットに変換し、  
i i) 少なくとも 1 つの送信機のそれぞれの送信アンテナによって送信された少なくとも 1 つの共通同期シーケンス毎に、前記周波数領域成分のセットから該送信アンテナに対応する受信された各トレーニングシーケンスを抽出し、  
i i i) 少なくとも 1 つの共通同期シーケンス毎に、受信された各共通同期シーケンスと周知の各共通同期シーケンスとの間の相関を計算し、  
i v) 相関を組み合わせて、候補同期位置毎に全体の相関結果を形成し、  
b) 相関の極大値である少なくとも 1 つのピークを相関において決定する、  
ことを含む、請求項 5 2 に記載の方法。

【請求項 5 4】

選択された送信機の前記微同期位置に基づいて、時間領域サンプルを周波数領域成分に再変換するとともに、その送信機における専用のパイロットチャネルに基づいて更なる微同期を行なうことを更に含む、請求項 5 3 に記載の方法。

【請求項 5 5】

ヘッダシンボルの副搬送波が複数のアンテナのそれぞれにおいて非連続の副搬送波のセットに分割され、各アンテナは、副搬送波の各セット上でのみヘッダシンボルを送信し、前

記ヘッダシンボルは、多重化されたパイロットチャネル副搬送波と、複数のアンテナのそれぞれにおいて共通同期チャネル副搬送波とを含み、前記フレームは、2つの同一のヘッダOFDMシンボルから始まり、そのヘッダOFDMシンボル中において、前記パイロットチャネル副搬送波のコンテンツが繰り返されるとともに、前記同期チャネル副搬送波のコンテンツが繰り返され、前記共通同期チャネル副搬送波は、1つの基地局のアンテナ毎に異なるが複数の基地局にわたって共通の複合シーケンスを搬送し、前記専用パイロットチャネル副搬送波のコンテンツは、少なくとも局所的に特定の基地局に固有のものである、ヘッダシンボルフォーマットを有するMIMO-OFDMフレームフォーマットに適用される、請求項54に記載の方法。

【請求項56】

送信機の切換えのため、そのように特定された送信機毎に、 $C/I$  または同様の値を所定の時間にわたって平均化し、その時間の最後に、現在選択されて送信されたものと異なる場合には、最も大きい平均 $C/I$  または同様の値を用いて前記送信機の送信機スイッチを起動させることを更に含む、請求項52に記載の方法。

## 【国際調査報告】

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A. CLASSIFICATION OF SUBJECT MATTER IPC 7 H04L1/06 H04L5/02 H04L27/26 H04B7/06 H04Q7/38		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) IPC 7 H04L H04B H04Q		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search process (date to be ind. where practical, search terms used) PAJ, WPI Data, EPO-Internal, INSPEC		
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<input checked="" type="checkbox"/> Further documents are listed in the continuation of box C. <input checked="" type="checkbox"/> Patent family members are listed in annex		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubt on priority claims or which is cited in evidence in the publication (date of publication or other special reason (as specified)) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principles or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or claimed be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "Z" document member of the same patent family		
Date of the actual completion of the international search 6 October 2003		Date of mailing of the international search report 12.11.2003
Name and mailing address of the ISA European Patent Office, P.O. Box 18 8251 Postfach 2 M - 2250 HW Hamburg Tel. (+31-20) 540-5040, Te. 51 851 epo nl Fax: (+31-77) 340-0916		Authorised officer Scriven, P

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PCT/JP 02/01542

C. (Continued) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	TUFVESSON ET AL.: "Time and frequency synchronization for OFDM using PN-sequence preambles" IEEE VEHICULAR TECHNOLOGY CONFERENCE, 19 - 22 September 1999, pages 2203-2207, XP000895004 New York, US figure 2	32-49
A	---	52-56
X	MÜLLER-WEINFURTER: "Frequency-domain frame synchronization for optimum frequency-differential demodulation of OFDM" IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE, 5 - 9 December 1999, pages 857-862, XP000956736 New York, US section 3	32-49
A	---	52-56
X, P	US 2002/122382 A1 (JIANGLEI MA ET AL.) 5 September 2002 (2002-09-05) paragraph [0008] paragraph [0038] paragraph [0039]	32-49
A	---	52-56
L	completes the disclosures of EP1185048 and of US2002/0122381	52-56
X, P	YINGJUN ZHANG ET AL.: "Multiuser subcarrier and bit allocation along with adaptive cell selection for OFDM transmission" IEEE INTERNATIONAL CONFERENCE ON COMMUNICATIONS, 28 April 2002 (2002-04-28) - 2 May 2002 (2002-05-02), pages 861-865, XP010539516 New York, US page 862, right-hand column, paragraph 4 * section IV *	52-56
A	---	52-56
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INTERNATIONAL SEARCH REPORT		International Application No. PCT/JP 02/01542
C. (Communication) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	HENRY, KORI: "DECT based rural radio local loop for developing countries" IEEE CONFERENCE ON PERSONAL WIRELESS COMMUNICATIONS, 19 - 21 February 1996, pages 44-46, XP010158284 New York, US ISBN: 0-7803-3177-X page 45, left-hand column, paragraph 2 -----	52-56

Form PCT/ISA/210 (2nd edition) July 2000

INTERNATIONAL SEARCH REPORT		International application No. PCT/CA 02/01542
<b>Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)</b>		
This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:		
1.	<input type="checkbox"/> Claims Nos.: because they relate to subject matter not required to be searched by this Authority, namely:	
2.	<input checked="" type="checkbox"/> Claims Nos.: 11-23 because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically: see FURTHER INFORMATION sheet PCT/ISA/210	
3.	<input type="checkbox"/> Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(b).	
<b>Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)</b>		
This International Searching Authority found multiple inventions in this international application, as follows:		
see additional sheet		
1.	<input checked="" type="checkbox"/> As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.	
2.	<input type="checkbox"/> As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.	
3.	<input type="checkbox"/> As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:	
4.	<input type="checkbox"/> No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:	
<div style="display: flex; justify-content: space-between; align-items: flex-start;"> <div style="margin-top: 10px;"> <p style="margin: 0;">Remark on Protest</p> <p style="margin: 0;"><input type="checkbox"/> The additional search fees were accompanied by the applicant's protest.</p> <p style="margin: 0;"><input checked="" type="checkbox"/> No protest accompanied the payment of additional search fees.</p> </div> </div>		

Form PCT/ISA/210 (continuation of first sheet (1)) (July 1998)

International Application No. PCT/CA 02/01542

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-23, 50-51

Header format and training sequence for MIMO-OFDM transmission

2. Claims: 24-31

Packet data frame structure

3. Claims: 32-49

Synchronisation in an OFDM receiver

4. Claims: 52-56

Cell selection

International Application No. PCT/CA 02/01542

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 218

Continuation of Box 1.2

Claims Nos.: 11-23

Claims 11-14 each refer back to a previous claim, in which no preamble is defined. The reference to 'said preamble' in these claims, therefore, is unclear, and it is not possible to determine the subject matter they seek to define.

Claims 15-23 seek to define a receiver. However, none of these claims defines any specific feature of a receiver. Each refers only to features of the received signal. Since it seems entirely possible to receive these signals with a standard WIMO receiver, it is not apparent which features are necessary to make such a receiver 'adapted to receive [the ] header format'. It is, therefore, not possible to determine the subject matter these claims seek to define.

Claims 24-30 seek to define a transmitter, but do not do so in terms of the technical features of a transmitter. The only technical features given define a signal, rather than a transmitter. Therefore, the search for the subject matter of these claims has been directed to a signal, rather than to a transmitter. Similarly, claim 31 seeks to define a receiver, but fails to do so in terms of the technical feature the receiver must have. The search for the subject matter of this claim has also been directed to the signal.

The applicant's attention is drawn to the fact that claims, or parts of claims, relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 56.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure.

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(72)発明者 チャ, ミン

カナダ国, ケー2 ビー 5 ビー3 オンタリオ, オタワ, クロイドン アヴェニュー 609-320

(72)発明者 チュー, ペイイン

カナダ国, ケー2 エム 2 エル4 オンタリオ, カナタ, ヘブル クリーク クレセント 16

(72)発明者 トン, ウエン

カナダ国, ケー2 シー 4 エー7 オンタリオ, オタワ, ホワイトストーン ドライヴ 12

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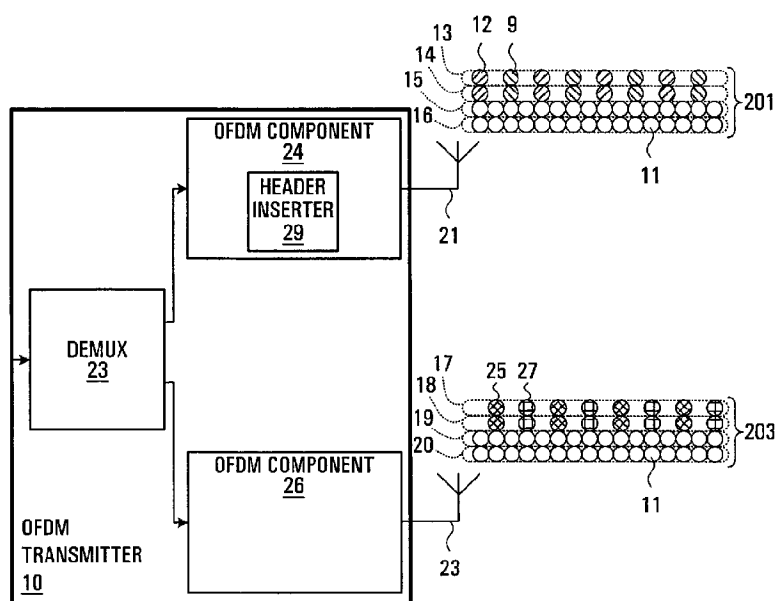
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- (71) Applicant: **NORTEL NETWORKS LIMITED**  
[CA/CA]; 2351 Boulevard Alfred-Nobel, St. Laurent, Quebec H4S 2A9 (CA).
- (72) Inventors: **MA, Jianglei**; 3 Bon Echo Cres., Kanata, Ontario K2M 2W5 (CA). **JIA, Ming**; 609-320 Croydon Avenue, Ottawa, Ontario K2B 5P3 (CA). **ZHU, Peiying**; 16 Pebble Creek Cres., Kanata, Ontario K2M 2L4 (CA). **TONG, Wen**; 12 Whitestone Drive, Ottawa, Ontario K2C 4A7 (CA).
- (74) Agents: **BRETT, R., Allan** et al.; Smart & Biggar, 900-55 Metcalfe Street, P.O. Box 2999, Station D, Ottawa, Ontario K1P 5Y6 (CA).
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[Continued on next page]

(54) Title: SYSTEM ACCESS AND SYNCHRONIZATION METHODS FOR MIMO OFDM COMMUNICATIONS SYSTEMS AND PHYSICAL LAYER PACKET AND PREAMBLE DESIGN



(57) Abstract: A method and apparatus are provided for performing acquisition, synchronization and cell selection within an MIMO-OFDM communication system. A coarse synchronization is performed to determine a searching window. A fine synchronization is then performed by measuring correlations between subsets of signal samples, whose first signal sample lies within the searching window, and known values. The correlations are performed in the frequency domain of the received signal. In a multiple-output OFDM system, each antenna of the OFDM transmitter has a unique known value. The known value is transmitted as pairs of consecutive pilot symbols, each pair of pilot symbols being transmitted at the same subset of sub-carrier frequencies within the OFDM frame.

- ⊗ -DEDICATED PILOT CHANNEL FOR ANT#1
- ⊗ -DEDICATED PILOT CHANNEL FOR ANT#2
- ⊗ -COMMON SYNCHRONIZATION CHANNEL FOR ANT#1
- ⊗ -COMMON SYNCHRONIZATION CHANNEL FOR ANT#2





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SYSTEM ACCESS AND SYNCHRONIZATION METHODS FOR MIMO OFDM  
COMMUNICATIONS SYSTEMS AND PHYSICAL LAYER PACKET AND  
PREAMBLE DESIGN

FIELD OF THE INVENTION

5           This invention relates to cellular wireless communication systems, and more particularly to system access within cellular wireless communication systems employing OFDM or OFDM-like technology, and to physical layer packet and preamble designs.

10 BACKGROUND OF THE INVENTION

          In a wireless communication system having at least one transmitter and at least one receiver, the receiver must acquire the timing of a signal transmitted by the transmitter and synchronize to it before information can be  
15   extracted from the received signal. The timing of signals transmitted from a base station, within a wireless communication system, is commonly referred to as the system timing.

          In cellular wireless communication systems  
20   employing Orthogonal Frequency Division Multiplexing (OFDM), synchronization to the timing of a signal enables the exact positioning of a Fast Fourier transform (FFT) window utilised by a receiver of the signal to extract information from the signal.

25           In any cellular wireless communication system having multiple base stations (BTS) and multiple mobile communication devices the synchronization process must occur frequently between the BTS and the mobile communication devices for the system to be operable. The mobile  
30   communication devices will simply be referred to hereinafter as UE (user equipment).

Furthermore, each BTS defines a geographic transmission region, known commonly as a cell, in which UE in substantially close proximity to a particular BTS will access the wireless communication system. The process  
5 whereby a particular UE selects a BTS from which to access the cellular wireless communication system is known as cell selection. In order to optimize the reception of the BTS signal, the UE needs to identify the best quality signal received from different BTSs and switch its receiver to tune  
10 into the best BTS for a given time. Thus, due to the mobility of UE, the synchronization process has to be employed frequently in order to allow seamless handoffs from one BTS to another BTS as the UE changes location.

In most current cellular wireless communication  
15 systems, fast system access and cell selection are essential functions for proper mobile UE operation. The objective of fast acquisition is to allow UE to synchronize into the desired BTS. The cell selection and re-selection is performed by UE to synchronize and measure the signal  
20 (including the interference) power among the adjacent BTS and select and switch to the BTS with the best signal quality, namely the maximum C/I (carrier-to-interference) ratio.

Existing solutions to access a wireless  
25 communication system employing OFDM (Orthogonal Frequency Division Multiplexing) were designed for wireless LAN (local area network) systems for fast packet access under a SISO (single input - single output) configuration. However, the wireless LAN does not have the capability to deal with the  
30 UE mobility, which requires seamless BTS handoff. On the other hand some cellular systems e.g. 3G UMTS are capable of performing cell selection and BTS identification and BTS C/I ratio measurement.

Multiple Input Multiple Output - Orthogonal Frequency Division Multiplexing (MIMO-OFDM) is a novel highly spectral efficient technology used to transmit high-speed data through radio channels with fast fading both in  
5 frequency and in time. For a high-speed downlink packet data transmission system, the design of the physical layer packet structure is a fundamental aspect.

OFDM technology has been adopted by DAB, DVB-T and IEEE 802.11 standards. DAB and DVB-T are used for audio and  
10 video territorial broadcasting. In these systems, the signal is transmitted in a continuous data stream. A preamble is not needed because fast packet access is not critical. DAB and DVB-T are also applied in single frequency networks. In this case, every transmitter  
15 transmits the same signal as a simulcast. The interference from the neighbouring transmitters can be treated as an active echo, which can be handled by the proper design of the prefix. IEEE 802.11 is the wireless LAN standard. It is a packet based OFDM transmission system. A preamble header  
20 is introduced in this standard.

Synchronization within MIMO-OFDM (Multiple Input Multiple Output-OFDM) systems, in which each transmitter and each receiver have multiple antennae, is even more difficult. Adding to the complexity of the task is that a  
25 fast synchronization process must be very reliable at very low C/I ratio conditions to allow a high rate of success for the entire cell. In addition, high mobility causes a high Doppler spread and this makes reliable synchronization even more difficult.

30 In MIMO-OFDM systems, synchronization can be performed in two steps. First, frame synchronization (also called coarse synchronization) is performed in order to determine the approximate range of the location of the

starting position of the first OFDM symbol in the frame.  
Second, timing synchronization (also called fine  
synchronization) is performed to determine the precise FFT  
window location, so that demodulation in the frequency  
5 domain can be performed accurately.

Conventionally, fine synchronization is  
implemented in time domain. This is achieved by inserting an  
a priori known pilot training sequence in the time domain  
for the receiver to perform the cross correlation computing  
10 at select time slots.

For example, as shown in Figures 1A and 1B, the  
OFDM frame structure of the IEEE 802.11 standard utilizes  
several repeated short OFDM symbols generally indicated at 5  
arranged as several headers in the time domain at the  
15 beginning of the frame for select sub-carriers, followed by  
training OFDM symbols 207 for fine synchronization. The  
headers 5 are used for frame (i.e. course) synchronization.  
The training OFDM symbols 207 are used to position the FFT  
window precisely so that demodulation in the frequency  
20 domain can be performed accurately. The training OFDM  
symbols 207 are followed by a TPS OFDM symbol 205 and data  
OFDM symbols 30.

The TPS (transmission parameter signalling) OFDM  
symbol 205, shown more clearly in the frequency domain (see  
25 Figure 1B), is transmitted with a frequency that corresponds  
to an adaptive coding and modulation period. The training  
OFDM symbols, TPS OFDM symbol and data OFDM symbols use all  
sub-carriers. In the 802.11 system, the repeated headers  
for course synchronization are only transmitted on every  
30 fourth sub-carrier. This design is only suitable for a  
simple SISO OFDM system with only a single transmit antenna.  
For MIMO-OFDM system the preamble design is more complicated  
because of the existence of multiple transmit antennas.

Furthermore for mobile communications, an efficient preamble design is even more difficult because of the multi-cell environment, the requirement for initial access when no BTS information is available, BTS switching and even soft  
5 handoff.

Existing methods in the process of cell acquisition and synchronization employ a 3-step-synchronization approach adopted by UMTS WCDMA system, which requires a relatively long access time. While fine  
10 synchronization may be performed in the time domain, the self-interference of MIMO channels limits the performance of this approach under very low C/I conditions. Increasing the length of the correlation can enhance the performance of fine synchronization in the time domain but at the price of  
15 an increase in overhead and processing complexity. The existing designs are based on the time domain training sequence correlation for a single transmit antenna and a single receive antenna system. However, a straightforward extension of such a time domain synchronization approach  
20 will cause performance loss especially for low C/I ratio applications. The cause of the performance loss is the self-interference between the MIMO channels that is not easy to reduce in time domain.

## 25 SUMMARY OF THE INVENTION

One broad aspect of the invention provides a MIMO-OFDM transmitter adapted to transmit a header symbol format in which sub-carriers of a header OFDM symbol are divided into a non-contiguous set of sub-carriers for each of a  
30 plurality of antennas, with each antenna transmitting the header OFDM symbol only on the respective set of sub-carriers.

In some embodiments, there are  $N$  antennas and a different set of sub-carriers separated by  $N$  sub-carriers is assigned to each of the plurality of antennas.

5 In some embodiments, the header symbols contain a multiplexed dedicated pilot channel on dedicated pilot channel sub-carriers and common synchronization channel on common synchronization channel sub-carriers for each of the plurality of antennas.

10 In some embodiments, the header OFDM symbols further contain multiplexed broadcasting sub-carriers for each of the plurality of antennas.

In some embodiments, the transmitter is further adapted to transmit a preamble having a prefix, followed by two identical OFDM symbols having said header OFDM symbol  
15 format. In some embodiments, the prefix is a cyclic extension of the two identical OFDM symbols.

In some embodiments, the pilot channel has a BTS specific mapped complex sequence allowing efficient BTS identification.

20 In some embodiments, the common synchronization channel is designed for fast and accurate initial acquisition.

In some embodiments, the common synchronization channel is used for course synchronization and fine  
25 synchronization and the pilot channel is used for fine synchronization.

In some embodiments, the common synchronization channel is used to transmit a complex sequence which is different for each transmit antenna of one transmitter, but  
30 which is common for respective transmit antennas of different transmitters within a communications network.

In some embodiments, the transmitter is further adapted to transmit OFDM frames beginning with said preamble, and having scattered pilots throughout a remainder of the OFDM frame.

5           In some embodiments, during the preamble, for each of N transmit antennas, dedicated pilot channel sub-carriers are transmitted and common synchronization channel sub-carriers are transmitted and broadcasting channel sub-carriers are transmitted.

10           In some embodiments, the sub-carriers of the preamble OFDM symbols are organized as a repeating sequence of {dedicated pilot channel for each of N transmit antennas, common synchronization channel sub-carrier for each of N transmit antennas} arranged in a predetermined order.

15           In some embodiments, the sub-carriers of the preamble OFDM symbols are organized as a repeating sequence of {at least one dedicated pilot channel sub-carrier for each of N transmit antennas, at least one common synchronization channel sub-carrier for each of N transmit  
20 antennas, at least one broadcast channel sub-carrier} arranged in a predetermined order.

          Another broad aspect of the invention provides a MIMO-OFDM receiver adapted to receive a header symbol format in which sub-carriers of a header OFDM symbol are divided  
25 into a non-contiguous set of sub-carriers for each of a plurality of antennas, with each antenna transmitting the header OFDM symbol only on the respective set of sub-carriers.

          In some embodiments, the receiver is adapted to  
30 receive from N transmit antennas with a different set of sub-carriers separated by N sub-carriers assigned to each of the plurality of transmit antennas.



In some embodiments, the receiver is further adapted to perform fine synchronization on the basis of the common synchronization channel sub-carriers and/or the dedicated pilot channel sub-carriers.

5           Another broad aspect of the invention provides a transmitter adapted to transmit a packet data frame structure. The packet data frame structure has a superframe having a length corresponding to a synchronization period of a network; the superframe containing a plurality of radio  
10 frames; each radio frame containing a plurality of TPS (transmission parameter signalling) frames corresponding to an adaptive coding and modulation period; each TPS frame containing a plurality of slots corresponding to an air interface slot size; each slot containing a plurality of  
15 OFDM symbols, with the first two symbols of the first slot of the first TPS frame of each OFDM frame being used as header OFDM symbols.

In some embodiments, the header OFDM symbols have a header OFDM symbol format in which sub-carriers of a  
20 header OFDM symbol are divided into a non-contiguous set of sub-carriers for each of a plurality of antennas, with each antenna transmitting the header OFDM symbol only on the respective set of sub-carriers.

In some embodiments, the header OFDM symbols  
25 contain multiplexed pilot channel sub-carriers and common synchronization channel sub-carriers for each of the plurality of antennas.

In some embodiments, the header OFDM symbols further contain multiplexed broadcasting channel sub-  
30 carriers for each of the plurality of antennas.

In some embodiments, the transmitter is further adapted to transmit in a plurality of different modes by

transmitting a different number of OFDM symbols per slot with an unchanged slot duration and with no change to the frame structure above the slot.

In some embodiments, wherein modes with an  
5 increased number of OFDM symbols per slot are realized by shortening OFDM symbol duration, and shortening FFT size, but not changing sampling frequency.

In some embodiments, the transmitter is further adapted to transmit to a respective set of users for each  
10 TPS frame and to signal for each TPS frame which users should demodulate the entire TPS frame.

Another broad aspect of the invention provides a method of performing synchronization at an OFDM receiver. The method involves, at each of at least one receive  
15 antenna, sampling a received signal to produce a respective set of time domain samples; determining at least one course synchronization position; at each of the at least one receive antenna:

a) for each of a plurality of candidate  
20 fine synchronization positions about one of said at least one course synchronization position:

i) for each receive antenna  
positioning an FFT window to the candidate fine  
synchronization position and converting by FFT the time  
25 domain samples into a respective set of frequency domain components;

ii) for each said at least one  
transmit antenna, extracting a respective received training  
sequence corresponding to the transmit antenna from the sets  
30 of frequency domain components;

iii) for each transmit antenna,  
calculating a correlation between each respective received

training sequence and a respective known transmit training sequence;

iv) combining the correlations for the at least one transmit antennas to produce an overall correlation result for each candidate synchronization position;

b) determining a fine synchronization position from the plurality of correlation values;

combining the fine synchronization positions from the at least one receive antenna in an overall fine synchronization position.

In some embodiments, a course synchronization position is determined for each receive antenna and used for determining the respective fine synchronization position.

In some embodiments, a course synchronization position is determined for each receive antenna and an earliest of the positions is used determining the fine synchronization positions for all receive antennas.

In some embodiments, the course synchronization position is determined in the time domain for at least one receive antenna by looking for a correlation peak between the time domain samples over two OFDM symbol durations.

In some embodiments, the method is applied at an OFDM receiver having at least two antennas, and combining the fine synchronization positions from the at least one receive antenna in an overall fine synchronization position comprises selecting an earliest of the fine synchronization positions.

In some embodiments, sampling a received signal to produce a set of time domain samples is done for at least three OFDM symbol durations; determining at least one course synchronization position comprises performing a

course synchronization in the time domain by looking for a correlation peak between the time domain samples received over two OFDM symbol durations to identify a course synchronization position by:

- 5                   a)           calculating a plurality of correlation values, each correlation value being a correlation calculated between a first set of time domain samples received during a first period having one OFDM symbol duration and a second set of time domain samples received  
10                   during a second period immediately following the first period and having OFDM symbol duration, for each of a plurality of starting times for said first period;
- b)           identifying the course synchronization position to be a maximum in said plurality of correlation  
15                   values.

                  In some embodiments, combining the correlations for the at least one transmit antennas to produce an overall correlation result for each candidate synchronization position comprises multiplying together the correlations for  
20                   the at least one transmit antenna for each candidate synchronization position.

                  In some embodiments, the method is applied to a single transmit antenna single receive antenna system.

                  In some embodiments, the training sequence is  
25                   received on common synchronization channel sub-carriers.

                  In some embodiments, the training sequence is received during an OFDM frame preamble.

                  In some embodiments, the training sequence is received on dedicated pilot channel sub-carriers.

30                   In some embodiments, the training sequence is received during an OFDM frame preamble.

Another broad aspect of the invention provides an OFDM receiver having at least one receive antenna; for each said at least one receive antenna, receive circuitry adapted to sample a received signal to produce a respective set of  
5 time domain samples; a course synchronizer adapted to determine at least one course synchronization position; a fine synchronizer comprising at least one FFT, at least one correlator and at least one combiner, adapted to, at each of the at least one receive antenna:

- 10           a)           for each of a plurality of candidate fine synchronization positions about one of said at least one course synchronization position:
  - i)           for each receive antenna  
position an FFT window to the candidate fine synchronization  
15 position and convert by FFT the time domain samples into a respective set of frequency domain components;
  - ii)          for each said at least one transmit antenna, extract a respective received training sequence corresponding to the transmit antenna from the sets  
20 of frequency domain components;
  - iii)         for each transmit antenna, calculate a correlation between each respective received training sequence and a respective known transmit training sequence;
  - 25           iv)         combine the correlations for the at least one transmit antennas to produce an overall correlation result for each candidate synchronization position;
- b)           determine a fine synchronization  
30 position from the plurality of correlation values;

the receiver being further adapted to combine the fine synchronization positions from the at least one receive antenna in an overall fine synchronization position.

In some embodiments, the receiver has at least two  
5 receive antennas, and is adapted to combine the fine synchronization positions from the at least one receive antenna in an overall fine synchronization position by selecting an earliest of the fine synchronization positions.

In some embodiments, the receiver is adapted to  
10 combine the correlations for the at least one transmit antennas to produce an overall correlation result for each candidate synchronization position by multiplying together the correlations for the at least one transmit antenna for each candidate synchronization position.

15 In some embodiments, the receiver is adapted to receive the training sequence on common synchronization channel sub-carriers.

In some embodiments, the receiver is adapted to receive the training sequence on dedicated pilot channel  
20 sub-carriers.

Another broad aspect of the invention provides a method of performing fine synchronization. The method involves, at each at least one receive antenna receiving OFDM symbols containing a respective received frequency  
25 domain training sequence for each of at least one transmit antenna; performing fine synchronization in the frequency domain by looking for maximum correlations between known frequency domain training sequences and the received frequency domain training sequences.

30 Another broad aspect of the invention provides a method of transmitting signals enabling fine synchronization. The method involves from each of at least

one transmit antenna, transmitting OFDM symbols containing a respective frequency domain training sequence.

In some embodiments, a different frequency domain training sequence is transmitted by each transmit antenna, but the same frequency domain training sequence is transmitted by corresponding antenna of other transmitters.

Another broad aspect of the invention provides a method of performing cell selection at an OFDM receiver. The method involves at each of at least one receive antenna, sampling a received signal to produce a respective set of time domain samples; determining at least one course synchronization position; at each of the at least one receive antenna:

a) performing a frequency domain correlation between at least one received common synchronization sequence extracted from common synchronization channel sub-carriers in the received signal and a corresponding common synchronization sequence of a respective plurality of transmit antennas to identify a plurality of candidate correlation peaks;

b) selecting the M strongest correlation peaks for further processing;

c) at each correlation peak, reconvert time domain samples into frequency domain components and processing pilot channel sub-carriers, these containing transmitter specific information, to identify a transmitter associated with each correlation peak;

d) determining a C/I or similar value for each transmitter thus identified;

selecting the transmitter having the largest C/I determined for any of the at least one receive antenna.

In some embodiments, performing a frequency domain correlation between at least one received common synchronization sequence extracted from common synchronization channel sub-carriers in the received signal and a corresponding common synchronization sequence of a respective plurality of transmit antennas to identify a plurality of candidate correlation peaks comprises:

- a) for each of a plurality of candidate fine synchronization positions about one of said at least one coarse synchronization position:
  - i) for each receive antenna positioning an FFT window to the candidate fine synchronization position and converting by FFT the time domain samples into a respective set of frequency domain components;
  - ii) for each of at least one common synchronization sequence, each common synchronization sequence having been transmitted by a transmit antenna of each of at least one transmitter, extracting a respective received training sequence corresponding to the transmit antennas from the sets of frequency domain components;
  - iii) for each of the at least one common synchronization sequence, calculating a correlation between each respective received common synchronization sequence and a respective known common synchronization sequence;
  - iv) combining the correlations to produce an overall correlation result for each candidate synchronization position;
- b) determining at least one peak in the correlations, each said at least one peak being local maxima in the correlations.



In some embodiments, the method further involves reconvert time domain samples into frequency domain components based on the fine synchronization position of the selected transmitter and performing a further fine  
5 synchronization based on a dedicated pilot channel for that transmitter.

In some embodiments, the method is applied to a MIMO-OFDM frame format having a header symbol format in which subcarriers of a header symbol are divided into a non-  
10 contiguous set of subcarriers for each of a plurality of antennas, with each antenna transmitting header symbols only on the respective set of sub-carriers, and wherein the header symbols contain multiplexed pilot channel sub-carriers and common synchronization channel sub-carriers for  
15 each of the plurality of antennas, the frame beginning with two identical header OFDM symbols during which contents of the pilot channel sub-carriers are repeated and contents of the synchronization channel sub-carriers are repeated, the common synchronization channel sub-carriers carrying a  
20 complex sequence which is different for respective antenna of one base station and being common across multiple base stations, and contents of the dedicated pilot channel sub-carriers being at least locally unique to a particular base station.

25 In some embodiments, the method further involves for transmitter switching, averaging the C/I or similar value over a time interval for each transmitter thus identified, and at the end of the time interval instigating a transmitter switch to the transmitter with the largest  
30 average C/I or similar value if different from a currently selected transmitted.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention will now be described in greater detail with reference to the accompanying diagrams, in which:

Figure 1A is the frame structure of IEEE 802.11  
5 standard in the time domain;

Figure 1B is the frame structure of Figure 1A in the frequency domain;

Figure 2A is a packet data frame structure provided by an embodiment of the invention;

10 Figure 2B is a packet frame hierarchy provided by an embodiment of the invention;

Figure 3 is a proposed header structure provided by an embodiment of the invention;

Figure 4 is a preamble header structure in the  
15 time domain provided by an embodiment of the invention;

Figure 5 is a preamble header structure in the frequency domain provided by an embodiment of the invention;

Figure 6 is a conceptual schematic view of a MIMO-OFDM transmitter provided by an embodiment of the invention;

20 Figure 7A is a block diagram of a MIMO-OFDM coarse synchronization functionality;

Figure 7B is a block diagram of a MIMO-OFDM fine synchronization functionality;

Figure 8 is a plot of a signature sequence  
25 correlation output for pilot channel showing several candidate synchronization position;

Figure 9 is a plot of a BTS identification simulation; and

Figure 10 is a flowchart of a method for cell selection and re-selection for MIMO-OFDM provided by an embodiment of the invention.

## 5 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to Figure 2A, an OFDM packet frame structure provided by an embodiment of the invention is shown. Transmit OFDM symbol streams are organised into such frames. Each frame consists of three major components:  
10 preamble 300, scattered pilots 302, and traffic data symbols 304. The insertion of the preamble allows UE (user equipment) to perform the following fundamental operations: fast BTS (base station) access, BTS identification and C/I ratio measurement, framing and timing synchronization,  
15 frequency and sampling clock offset estimation and initial channel estimation. The design of a frame preamble with minimized overhead is critical to maximum spectral efficiency and radio capacity.

Referring now to Figure 2B, a frame hierarchy for  
20 MIMO-OFDM is organized according to an embodiment of the invention as follows: at the highest level are OFDM superframes 500 (two shown). The duration of the superframe is determined by the network synchronization period (for example 1-second). The superframe is composed of several  
25 ms radio frames 502 also referred to as OFDM frames. There would be 100 10 ms OFDM frames 502 in a 1s superframe 500.

To support adaptive coding modulation (ACM), a fast signalling channel (TPS channel-transmission parameter signalling) is introduced. Each OFDM frame 502 is  
30 subdivided into TPS frames 504, in the illustrated example there are five 2 ms TPS frames for each 10 ms radio frame 502. The frame length used for TPS in some embodiments is

the same as the duration of the ACM unit. Each TPS frame also contains signalling information which allows each user to determine whether the current TPS frame contains data for them or not. A TPS frame may contain data for multiple  
5 users.

The TPS frame 504 can be divided further into several slots 506, each of which consists of several OFDM symbols. In the illustrated example, each TPS frame 504 is subdivided into 3 slots 506. The duration of the slot 506  
10 depends upon the air interface slot size. The smallest transmission unit is one OFDM symbol 508, 510. The duration of one OFDM symbol is determined by the transmission environment characteristics, for example, the maximum channel delay, the system-sampling clock and the maximum  
15 Doppler. In the illustrated example, there are four OFDM symbols 508, 510 per slot 506.

To reduce the overhead caused by the insertion of the guard interval between OFDM symbols, different OFDM symbol modes each with a different symbol duration and a  
20 different prefix can be designed, for example, 0.5k mode and 1k mode. To simplify the system the sampling frequency is kept unchanged when doing the mode switching. These different modes are described in more detail below.

The frame structure of Figure 2B gives an example  
25 of a frame structure hierarchy compatible to the UMTS air-interface. At the OFDM symbol level, there are two different types of OFDM symbols. These include the preamble OFDM symbols 508 and regular data symbols 510.

Referring now to Figure 4, which is a time domain  
30 representation, each OFDM frame starts with a preamble, which consists of several identical header OFDM symbols 603, 605 preceded by a prefix 607 which is a cyclic extension of the header OFDM symbols. A repetition structure is used to

assist synchronization. By performing a correlation between adjacent OFDM symbols until two identical symbols are identified, the start of an OFDM frame can be found. By way of example, there may be 1056 samples used per OFDM symbol.

5 For the preamble, during the prefix 607, the last 64 samples of the header OFDM symbols are transmitted. There is no prefix for the second header OFDM symbol. The header is inserted periodically, and for the example of Figure 2B, this occurs every 10 ms, i.e. at the beginning of every OFDM  
10 frame.

Referring again to Figure 2B, it is noted that for non-header OFDM symbols, i.e. for the regular OFDM symbols 510, every OFDM symbol preferably also has a prefix. In "1K" mode, there are 32 prefix samples, and 1024 actual  
15 samples representing the FFT size, for a total of 1056 samples per symbol. In 1/2K mode, there is a 16 sample prefix, and then 512 samples per symbol (representing the FFT size) for a total of 528 samples/symbol.

Advantageously, using the frame structure of Figure 2B these  
20 different modes can be supported without changing the sampling frequency. When in 1/2K mode, there are twice as many OFDM symbols 510 per slot 506. The particular mode chosen at a given instant should be such that the prefix size is greater than the maximum channel delay. in 1/K  
25 mode, more OFDM symbols are sent with fewer sub-carriers. This is more robust to high Doppler, because the symbol duration is shorter. Also, the spacing between the sub-carriers is larger further enhancing tolerance to Doppler. Thus, there is a unified frame structure which accommodates  
30 different FFT sizes, but with the same sampling rate at the receiver. Preferably the same preamble is used even for the different modes.

OFDM is a parallel transmission technology. The whole useful bandwidth is divided into many sub-carriers, and each sub-carrier is modulated independently. According to an embodiment of the invention, to separate different antenna with multiple antennas transmission, during the header not all sub-carriers are used on all transmit antennas. Rather, the sub-carriers are divided between antennas. An example of this will now be described with reference to Figure 3. The sub-carrier frequencies contained within an OFDM symbol are each represented by circles. In this example it is assumed that there are two transmitting antennas in the MIMO system. Figure 3 shows OFDM symbols with the various sub-carriers spaced along the frequency axis 400, and with the contents of all the sub-carriers at a given instant representing one symbol in time, as indicated along the time axis 402. In this case, the first two OFDM symbols 408, 410 are used for dedicated pilot channel information while the remaining symbols (only two shown, 412, 414) are used for regular OFDM symbols. The dedicated pilot channel information transmitted on the first two OFDM symbols 408, 410 alternates by sub-carrier between being transmitted by the first antenna and the second antenna. This is indicated for the first sub-carrier 404 which is transmitting dedicated pilot channel information for the first transmitter and sub-carrier 406 which is transmitting dedicated pilot channel information for the second sub-carrier, and this pattern then repeats for the remainder of the sub-carriers. The other OFDM symbols 412, 414 contain information transmitted by both antennas. It is to be understood that other spacings could alternatively be used. Furthermore, if there are more than two transmit antennas, the pilot channel information would then alternate by sub-carrier in some predetermined pattern between all of the transmit antennas.

In another embodiment, a common synchronization channel, and dedicated pilot channel are frequency multiplexed onto the header symbols. A respective set of non-overlapping sub-carriers are assigned for each antenna  
5 to transmit respective dedicated pilot channel and common synchronization channel.

In another embodiment a common synchronization channel, dedicated pilot channel and a broadcasting channel are frequency multiplexed onto the header symbols. Under  
10 this arrangement, the total useful sub-carriers of the header symbols are separated into three groups. These three groups are mapped onto the common synchronization channel, dedicated pilot channel and the broadcasting channel respectively.

15 An example of the mapping of the different channels in the MIMO-OFDM system with two-transmitter diversity is shown in Figure 5. In this example, there are shown four OFDM symbols 712, 714, 716, 718 two of which 712, 714 are header symbols. During the header symbols 712, 714  
20 every second sub-carrier is used for the first antenna with the remaining sub-carriers used for the second antenna. This is easily generalized to higher numbers of antennas. For this example, it is assumed that there are two transmit antennas in the MIMO system. Every sixth sub-carrier  
25 starting at the first sub-carrier 700 is for the first transmitter dedicated pilot channel sub-carriers. Every sixth sub-carrier starting at the second sub-carrier 702 is for the second transmitter dedicated pilot channel sub-carrier. Every sixth sub-carrier starting at the third sub-  
30 carrier 704 is for the first transmitter common synchronization channel sub-carrier. Every sixth sub-carrier starting at the fourth sub-carrier 706 is for the second transmitter common synchronization channel sub-

carrier. Every sixth sub-carrier starting at the fifth sub-carrier is for broadcasting channel sub-carriers for the first antenna, and every sixth sub-carrier starting at the sixth sub-carrier 710 is for broadcasting channel sub-carriers for the second antenna.

The common synchronization channel is a universal channel for initial access. It can also be used for synchronization and preliminary channel estimation. The different transmitters share the common synchronization sub-carriers when transmitter diversity is applied. In which case as indicated above the common synchronization channel is divided between different transmitters. A common complex sequence known by all the terminals is used to modulate the sub-carriers reserved for the common synchronization channel. The same common synchronization sequence is transmitted by all base stations within a system. There may be one or more such synchronization sequences in the event that there are multiple transmit antennas such that each transmit antenna can transmit a unique synchronization sequence. Using the synchronization sequence, mobile stations are able to find initial synchronization positions for further BTS identification by looking for a correlation peak between received synchronization sequence and the known transmitted synchronization sequence.

The dedicated pilot channel is used for BTS/cell identification, and supports C/I measurement for the cell selection, cell switching and handoff. A unique complex sequence, for example a PN code, is assigned to each BTS and used to modulate the dedicated pilot sub-carriers. A different unique sequence is transmitted by each antenna in the multiple transmit antenna case. Unlike the case for the common synchronization channel, different base stations transmit using different pilot sequences. The quasi-



orthogonality of the PN codes assigned to different BTSs makes it possible to do access point identification and initial interference measurement. The dedicated pilot channel can also be used to assist the synchronization  
5 processing.

To fully utilize the sub-carriers in the header OFDM symbols, as indicated above, some sub-carriers are preferably used as a broadcasting channel. In the example of Figure 5, two of every six sub-carriers are used for this  
10 purpose. The broadcasting channel can carry important system information. STTD (space time transmit diversity) schemes cannot be used for the broadcasting channel (or any of the sub-carriers in the header OFDM symbols) because of it will destroy the repetition structure of the header OFDM  
15 symbols which is required by synchronization algorithms. However transmitting the broadcasting information by all transmitters on the same sub-carrier may cause destructive interference between transmitters. To solve that problem the broadcasting channel is partitioned between different  
20 transmitters, so in the two transmit antenna case, the sub-carriers (mapped for the broadcasting channel) can be assigned alternatively for the transmit antenna to provide diversity. Power boosting may be applied to further enhance the broadcasting channel.

25 The broadcasting information from different BTS's can be different. In some embodiments broadcasting information is protected so those users close to the cell boundaries can receive it correctly in the presence of strong interference. A short PN code could be used to  
30 spread the broadcasting information. The neighbouring BTS is assigned to use different code. The insertion of the broadcasting channel reduces the preamble overhead and increases the spectrum efficiency.

The broadcast channel is used to transmit information unique to the particular base station. A single broadcast message may be sent on the combined broadcast channel carriers for the two antennas. By designing the preamble header symbol to consist of pilot channel, synchronization channel and the broadcasting channel, the preamble header overhead is reduced. The common synchronization channel is designed for fast and accurate initial acquisition. The dedicated pilot channel with a BTS specific mapped signature allows an efficient BTS identification. The combined common synchronization channel and the pilot channel are used together for MIMO channel estimation. The use of the combined common synchronization channel and the dedicated pilot channel also allows for high accuracy synchronization. Frequency domain training symbols are robust to timing error and multipath environments. The preamble design allows the flexibility of the user equipment to implement more efficient algorithms.

It is noted that the specific breakdown of sub-carriers between the dedicated pilot channel in one embodiment, between the dedicated pilot channel and common synchronization channel in another embodiment, and between the dedicated pilot channel, common synchronization channel and broadcast channels in another embodiment, are only specific examples. These can be allocated in any suitable manner.

Referring now to Figure 6, shown is a conceptual schematic of a MIMO-OFDM transmitter 10. A first sample set of four OFDM symbols 201 is shown transmitted from a first transmit antenna 21 and a second sample set of four OFDM symbols 203 is shown transmitted from a second transmit antenna 23. In general an OFDM transmitter will have  $N_{\text{ant}}$  transmit antennae, where  $N_{\text{ant}}$  is a design parameter. Within

the MIMO-OFDM transmitter 10, data originating from a demultiplexer 23 are sent to one of either a first OFDM component 24 connected to transmit antenna 21 or a second OFDM component 26 connected to transmit antenna 23. The components organize the data onto sub-carriers of OFDM symbols and OFDM frames, each sub-carrier being at a different orthogonal frequency. Each OFDM component 24,26 has a respective header inserter 29 which inserts header OFDM symbols. The sample sets of OFDM symbols 201 and 203 represent the first four OFDM symbols of the transmitted OFDM frame from transmit antennae 21 and 23, respectively, where each row of data symbols or pilot symbols is an OFDM symbol. A first OFDM symbol 13 and a second (identical to the first) OFDM symbol 14 represent the two header OFDM symbols unique to the OFDM frame transmitted by first transmit antenna 21. Similarly, a third OFDM symbol 17 and a fourth (identical to the third) OFDM symbol represent the two header OFDM symbols unique to the OFDM frame transmitted by the second transmit antenna 23. Four OFDM symbols 15, 16, 19, 20 are typically non-identical OFDM symbols made up of a plurality of data symbols, with at least one data symbol indicated generally at 11 on each OFDM sub-carrier. An entire OFDM frame would typically have many more data symbols. Also, the OFDM symbols 201 are transmitted concurrently, and with the same timing, as OFDM symbols 203.

In this example, the two identical header OFDM symbols consist of dedicated pilot channel sub-carriers 12 and common synchronization channel sub-carriers 9. There may also be broadcast channel sub-carriers, not shown. The dedicated pilot channel sub-carriers are used for C/I ratio measurement and BTS identification and fine synchronization as detailed below; they can also be used for initial channel estimation. The common synchronization channel sub-carriers 9 are used for course synchronization and fine

synchronization, initial access, and initial channel estimation.

In the illustrated example, during the two header OFDM symbols, the first of every four consecutive sub-carriers is used to carry dedicated pilot channel symbols transmitted by transmitting antenna 21. Similarly, the second of every four consecutive sub-carriers is used to carry dedicated pilot channel symbols transmitted by transmitting antenna 23.

10           The dedicated pilot channel symbols transmitted on the pilot channel sub-carriers 12, 25 are defined by base station/sector specific PN sequence. A set of symbols from a complex pseudo-random PN sequence unique to the base station is mapped onto the dedicated pilot channel sub-carrier locations in the header OFDM symbols.

15           The third of every four consecutive sub-carriers in the two header symbols is used to carry common synchronization channel symbols transmitted by transmitting antenna 21. Similarly the fourth of every four consecutive sub-carriers is used to common synchronization channel symbols transmitted by transmitting antenna 23.

20           The common synchronization channel symbols transmitted on the common synchronization sub-carriers 9, 27 are defined by unique complex pseudo-random PN sequence for each transmit antenna 21 and 23. A set of symbols from this complex pseudo-random PN sequence is mapped onto the common synchronization channel sub-carriers in the header OFDM symbols. That is, the common synchronization channel symbols of each frame transmitted through each transmitting antenna use a PN code unique to that transmitting antenna but which is the same for corresponding transmitting antennas of other base stations. In the present example  
30            $PN_{\text{SYNC}}^{(1)}$  is associated with transmit antenna 21 and  $PN_{\text{SYNC}}^{(2)}$  is

associated with transmit antenna 23. However, similar antennae in different transmitters throughout the communication network will use the same PN code. For example, the common synchronization channel symbols for a first transmit antenna 21 on all transmitters within the network will use one PN code ( $PN_{\text{SYNC}}^{(1)}$ ), and the common synchronization channel symbols for a second transmit antenna 22 on all transmitters within the network will use a different PN code ( $PN_{\text{SYNC}}^{(2)}$ ).

Referring to Figure 7A, a block diagram of MIMO-OFDM receiver functionality is shown which is adapted to perform coarse synchronization based on the two repeated OFDM header symbols transmitted by each transmit antenna as detailed above. The OFDM receiver includes a first receiving antenna 734 and a second receiving antenna 735 (although more generally there will be a plurality of  $N$  receiving antennae). The first receiving antenna 734 receives a first received signal at RF receiver 736. The first received signal is a combination of the two signals transmitted by the two transmitting antennae 21 and 23 of Figure 6, although each of the two signals will have been altered by a respective channel between the respective transmitting antenna and the first receiving antenna 734. The second receiving antenna 735 receives a second received signal at RF receiver 739. The second received signal is a combination of the two signals transmitted by the two transmitting antennae 21 and 23, although each of the two signals will have been altered by a respective channel between the respective transmitting antenna and the second receiving antenna 735. The four channels (between each of the two transmitting antennae and each of the two receiving antennae) may vary with time and with frequency, and will in general be different from each other.

Coarse synchronization is performed for the first receive antenna 734 by a coarse synchronizer 737 on discrete time samples of a received signal to determine an approximate range of a location of the starting position of the first header symbol. A similar process is performed by course synchronizer 741 for the second antenna 735. Coarse synchronization is facilitated by the use of repeated header symbols at the OFDM transmitter. The coarse synchronizer 737 performs correlation measurements on time domain signal samples in successive OFDM symbols. The time domain signal sample yielding the highest correlation measurement is the coarse synchronization position  $n_{coarse}$ . The course synchronization position  $n_{coarse}$  is then used as the position on which to locate an FFT window within the FFT functions used in fine synchronization.

Initially, the coarse synchronizer 737 starts the time domain coarse synchronization processing. A running buffer (not shown) is used to buffer discrete time samples of the received signal over three successive OFDM symbol period, and then calculates the auto-correlation  $\gamma_t(n)$  between samples collected during two successive OFDM symbol durations as follows:

$$\gamma_t(n) = \sum_{i=0}^{N_{header}-1} x(n+i) x^*(n+i+N_{header})$$

where  $x(n)$  is the time domain samples of the received signal,  $N_{header}$  is the number of samples taken over one OFDM symbol duration.

In some embodiments, a moving correlator is applied in the real time implementation to save calculation power.

In one embodiment, the values of  $\gamma_t(n)$  are calculated in sequence, for  $n=1$  (until  $n = N_{header}$ ), until a

correlation value is above a threshold, after which a maximum search is enabled. The computation of the correlation values continues and the maximum search process will continue until the correlation result is below the  
5 threshold again. The sample position corresponding to the maximum correlation value is the coarse synchronization position:

$$n_{coarse} = \arg \max(|\gamma_t(n)|) \quad n \in \{\gamma_t(n) > \gamma_{threshold}\}$$

The threshold is typically calculated from the  
10 average auto-correlation values within one frame. Alternatively, another way of finding the maximum is to determine a local maximum for each OFDM symbol over an OFDM frame which might be 60 symbols in length for example. Then, the overall maximum is taken to be the maximum of the  
15 local maxima. This process is conducted both course synchronizers. In the event fine synchronization is to proceed jointly, the overall course synchronization position may be taken as some combination of the two synchronization values, and is preferably taken to be the earlier of two  
20 course synchronization positions thus determined. Alternatively, each fine synchronizer (detailed below) can work from a respective course synchronization position.

Referring to Figure 7B, a block diagram is shown of an MIMO-OFDM fine synchronization functionality is shown. In one  
25 embodiment, the fine synchronization functionality is adapted to perform fine synchronization based on the two-repeated OFDM header symbols transmitted by each transmit antenna as detailed above using the common synchronization channel and/or the dedicated pilot channel. More generally,  
30 the fine synchronization functionality can perform fine synchronization for OFDM frames within which some known training sequence has been embedded. Also, an input to the fine synchronization process is a course synchronization

position. This coarse synchronization position may be determined using the above discussed method, or using any other suitable method. The components which are identical to those of Figure 7A are similarly numbered and in an  
5 actual implementation would be shared if the common synchronizers of Figure 7A are to be used. The functionality of Figure 7B is replicated for each of the one or more receive antenna.

A fine synchronization process is performed for  
10 each of one or more receive antennae, and then an overall synchronization position is taken based on a combination of the fine synchronization positions. By way of overview, once the coarse synchronizers have determined the coarse synchronization position(s)  $n_{coarse}$ , each fine synchronizer  
15 performs an FFT on the signal samples on either side of the coarse synchronization position, to generate frequency domain components over the frequency band of OFDM sub-carriers. Each fine synchronizer searches the frequency domain components in order to locate the precise location of  
20 the FFT window. The precise location of the FFT window is required in order to perform OFDM demodulation in the frequency domain. The fine synchronizer locates the precise location of the FFT window by performing correlation measurements between the known PN codes ( $PN_{SYNC}^{(1)}$  &  $PN_{SYNC}^{(2)}$ )  
25 and the frequency components within a searching window defined with respect to the coarse synchronization position  $n_{coarse}$ . The correlation measurements performed by each fine synchronizer are performed in the frequency domain, and one set of correlation measurements is performed for each known  
30 PN code ( $PN_{SYNC}^{(1)}$  &  $PN_{SYNC}^{(2)}$ ), that is, for each transmitting antenna 21 and 23 (or for how many of the one or more transmit antenna there are).



Each fine synchronizer selects  $N_{\text{symbol}}$  signal samples starting at an initial signal sample within the searching window, where  $N_{\text{symbol}}$  is the number of signal samples in an OFDM symbol. For each transmitting antenna, 5 each fine synchronizer determines a correlation measurement between the frequency domain signal samples and the PN code corresponding to the transmitting antenna.

More specifically, fine synchronization searching is performed near  $n_{\text{coarse}}$ . Supposing that the searching window 10 is  $2N+1$ , the searching range is from  $(n_{\text{coarse}} - N)$  to  $(n_{\text{coarse}} + N)$ . Let  $n_{\text{start}}(i) = n_{\text{coarse}} + N - i$  represent the sample index within the fine searching window, where  $i=0, \dots, 2N$ . The fine synchronization starts from  $i=0$ . Then  $N_{\text{symbol}}$  samples are taken starting from  $n_{\text{start}}(0)$ , the prefix is removed and FFT 15 is performed. The received OFDM symbol in frequency domain can be written as:

$$R(l, i) = \text{FFT}(x(n(i), l)), n(i) = [n_{\text{start}}(i) + N_{\text{prefix}}, n_{\text{start}}(i) + N_{\text{symbol}} - 1]; l = 1, \dots, N_{\text{FFT}};$$

where  $N_{\text{prefix}}$  is the number of prefix samples and  $N_{\text{FFT}}$  is the FFT size.

20 From  $R$ , the complex data  $R^{(j, k)}_{\text{SYNC}}$  carried by the common synchronization channel of different transmitters is extracted, since common synchronization channels are divided between different transmitters in MIMO OFDM system. More generally, the complex the data corresponding to a 25 transmitted training sequence is extracted. The correlation between  $R^{(j, k)}_{\text{SYNC}}$  and  $PN^{*(j)}_{\text{SYNC}}$  is:

$$\gamma_f^{(j, k)}(i) = \sum_{m=0}^{N_{\text{SYNC}}-1} R^{(j, k)}_{\text{SYNC}}(m, i) \cdot PN^{*(j)}_{\text{SYNC}}(m), i = 0, \dots, 2N$$

where  $j=1, 2, \dots, N_{\text{Tx}}$  indicates transmitter,  $k=1, 2, \dots, N_{\text{Rx}}$  indicates receiver,  $PN^{(j)}_{\text{SYNC}}$  is the common SYNC PN code for 30  $j^{\text{th}}$  transmitter and  $N_{\text{SYNC}}$  is the size of common PN code.

Then the starting point index  $n_{start}$  is shifted by one ( $n_{start}(1) = n_{start}(0) - 1$ ), and another  $N_{symbol}$  samples are processed as described above. In order to get the new frequency domain data  $R^{(j,k)}_{SYNC}(m,i)$ , we need to perform FFT again. An iterative method can be used for this purpose to reduce the computational complexity:

$$R(l,i) = R(l,i-1) \cdot e^{i2\pi(k-1)/NFFT} + x(n_{start}(i) + N_{prefix}) - x(n_{start}(i-1) + N_{symbol} - 1)$$

where NFFT is the FFT size. Extracting  $R^{(j,k)}_{SYNC}(m,i)$ , the new correlation is calculated. The above procedure is continued until  $n_{start}$  moves out of the fine searching window.

For each

$$n_{fine} = \arg \max \left( \prod_{j=1}^{N_{Tx}} \prod_{l=1}^{N_{Rx}} |\gamma^{(j,k)}_f(i)| \right) \quad \begin{array}{l} \text{receive antenna, a} \\ \text{15 respective fine} \end{array}$$

synchronization position can be found by finding  $n_{start}(i)$  corresponding to the maximum of the products of the correlation results from different antennas over  $i = 0, \dots, 2N$ . In mathematical terms, for the  $k$ th receive antenna, a respective fine synchronization position can be selected according to:

$$n_{fine}(k) = \arg \max \left( \prod_{j=1}^{N_{Tx}} |\gamma^{(j,k)}(i)| \right)$$

To reduce the possibility of false alarm, a criterion may be set. For example, the fine synchronization may be considered to be achieved if the following condition is satisfied,

$$\max \left( \prod_{j=1}^{N_{Tx}} |\gamma^{(j,i)}(i)| \right) > N_{threshold} \cdot \frac{1}{2N+1} \cdot \sum_{i=0}^{2N} \prod_{j=1}^{N_{Tx}} |\gamma^{(j,i)}(i)|$$

where  $N_{threshold}$  is a factor determined by the pre-set fine searching window size. Preferably, an overall fine

synchronization position is then taken to be the earliest of the fine synchronization positions determined for the different receive antennas.

The fine synchronization process for one receive antenna is illustrated diagrammatically in Figure 7B. At the output of the first receiver 736, blocks D0 738 through D2N 742 represent alignment of the FFT blocks 744,...,748 for the various candidate fine synchronization positions ( $2N+1$  in all). The FFT blocks 744,...,748 compute an FFT on each respective set of samples. Each FFT output is fed to a correlator block for each transmit antenna. If there are two transmit antennae, then there would be two such correlator blocks per FFT output. For example FFT 744 has an output fed to a first correlator block 745 for the first transmit antenna, and fed to a second correlator block 755 for a second transmit antenna. It is noted that if the spacing of the sub-carriers used to transmit the training sequence (the common synchronization sequence or pilot channel sequence in the above examples), a full FFT does not need to be completed in order to recover the training sequence components. The correlator block 745 for the first antenna multiplies with multiplier 747 the recovered training sequence symbol locations of the FFT output by the known training sequence for the first transmit antenna and these multiplications are added in summer 751. This same computation done in correlator 755 for the known training sequence of the second transmit antenna and the training sequence locations for the second transmit antenna. This is done at the first receiver for all of the different possible shifts for each transmit antenna. The correlation results across different transmit antennas for each possible shift are multiplied together in multipliers 753. The shift which results in the maximum of these multiplications is selected to be the fine synchronization position for the particular

receiver. The same process is followed for any other receive antennas, and the overall fine synchronization position is preferably taken as the earliest of the fine synchronization positions thus computed.

5           The timing synchronization can be tracked every frame in case that the synchronization position drifts or losses. For example, in systems employing the previously described preamble, each time a preamble arrives at the receiver the 2-step process of synchronization is repeated,  
10 using the same method for coarse synchronization and fine synchronization. In this case, a smaller searching window  $N$  may be used based on the assumption that the drift of the synchronization position should be around the vicinity of the current location. After acquisition, the dedicated  
15 pilot channel code assigned to modulate dedicated pilot channels for different BTS can be used in the correlator, or the common synchronization sequence can be used, or some other training sequence.

          An embodiment of the invention has been described  
20 with respect to an MIMO-OFDM transmitter having more than one transmitting antenna. The method of performing synchronization at the OFDM receiver may also be applied to a signal received from an OFDM transmitter having only one transmitting antenna, as long as a known training sequence  
25 is inserted in the frame by the OFDM transmitter.

          Lastly, in the embodiment of the invention described thus far there has only been one transmitter having multiple antennae and one receiver having multiple antennae. In what follows, the concepts of the invention  
30 will be broadened to encompass the multi-cellular environment having many MIMO-OFDM transmitters and many MIMO-OFDM receivers.

Access in a Multi-Cellular Environment

System access in a multi-cellular environment introduces the new problem of cell selection, as there will be many transmitters transmitting the same common pilot symbols. In another embodiment of the invention, the  
5 previously introduced transmit header is used by receivers to perform systems access and cell selection.

During initial acquisition, the UE starts by performing coarse synchronization. This may be done using the previously described methods, or some other method.  
10 After one frame duration, the coarse synchronization position is determined. Fine synchronization search algorithm is performed afterwards based on the common synchronization channel. Because the data carried by the common synchronization channel are the same for all BTS,  
15 several fingers (peaks) can be observed in a multi-cell environment and multi-path fading propagation channels. These fingers usually correspond to different BTS and/or different paths. Referring to Figure 8, shown is an example of fine synchronization (to the common synchronization  
20 channel) raw output computed in a multi-cellular environment as a function of sample index. In the present example there are five significant fingers 400, 402, 404, 406, and 408. The M strongest fingers are chosen and the corresponding positions are located, where M is a system design parameter.  
25 These positions are used as candidates for final synchronization and also as the positions upon which BTS identifications are made.

The results of Figure 8 do not allow BTS identification because BTS transmit the same common  
30 synchronization sequences. At each candidate synchronization position, the correlations of the received dedicated pilot channel sub-carriers and all possible complex sequences (dedicated pilot PN sequences) assigned to

different BTS are calculated to scan for the presence of all the possible adjacent BTSS. In the multiple transmit antenna case, preferably this correlation is done on the basis of the combined dedicated pilot PN sequences of the multiple antennas over all of the dedicated pilot sub-carriers to generate a single correlation result for each index. Figure 9 shows an example of the relation between the BTS scanning results and the checking points (candidate synchronization positions). The BTS identification is realized by detecting the PN code corresponding to the maximum correlation value at each candidate synchronization position. C/I can be computed based on all correlation results at each checking position. At the initial acquisition stage, the cell selection is determined by selecting the BTS with the largest C/I ratio. In the present example two BTS are identified, a first BTS BTS1 and a second BTS BTS2. With multiple-antenna receiver diversity, the final decision of the cell selection should be based on the comparison of the highest C/I obtained by different receiver antennae at a receiver.

To obtain the final synchronization position, fine synchronization is performed again, but by using the dedicated pilot channel and the dedicated complex sequence found through the BTS identification. A smaller searching window around the fine synchronization position is used. The final synchronization results from different receivers are compared. The position corresponding to the earliest sample in time is used as the final synchronization position. This step is to reduce the possibility that a weak path (multi-path) is selected because of the short-term fading. To reduce the false alarm probability, a threshold is set. This threshold can be the ratio of the finger strength with respect to the final synchronization position and the average of the correlation within the search window.

In the normal data processing stage, the fine synchronization and the BTS identification steps are repeated every frame when a new preamble is received, but a small set of the candidate PN codes is applied in the BTS scan. After BTS identification, a BTS candidates list can be generated through searching strong interferences. This list is updated periodically, for example every 10 ms, and provides information for BTS switch and even soft handoff. Certain criteria can be set in order to trigger the BTS switch and soft handoff. To average the impact from the fading, the decision for BTS switching and the soft handoff may be based on observation during a certain period. The criteria can be the comparison of the maximum correlation values representing C and the strongest I. It should be noted that after the cell switch and the soft handoff, the synchronization may also be adjusted by the final step in the initial access. The overall cell selection and re-selection method is shown in Figure 10.

In the first step 600, coarse synchronization is performed for example based on the preamble header in the time domain. This involves finding a coarse boundary between each frame by looking for two identical symbols. Correlating samples over adjacent symbol durations until a peak is found does this. Step 600 relies on a preamble to a frame beginning with two adjacent identical symbols.

Next during step 602, at the coarse synchronization peaks, an FFT is computed, and a switch to the processing of the common synchronization channel in the frequency domain is made. A search window is centered on sync position +/- a certain number of samples. The M strongest correlation peaks are selected, as per 604. At this time, it is not known which BTS each peak is associated with. BTS identification has not yet been determined.

Then at step 606, for each correlation peak, the FFT is again computed and the correlations associated with the fine synchronization procedure are computed using the dedicated pilot channels - these containing a base station specific complex sequences. This is immediately followed by step 608 where the correlation with the BTS identification complex sequences is made in order to allow an identification of the associated base stations. At step 610, a C/I ratio is computed for each BTS thus identified. BTS selection and BTS switching is performed on the basis of these C/I ratios in step 612. As indicated above, BTS switching is performed on the basis of these C/I ratios averaged over some time interval.

Finally, for access, the FFT is computed and fine synchronization is applied to the dedicated pilot channel of the BTS with the largest C/I ratio as per step 614.

BTS initial synchronization performed on the common synchronization channel. A BTS specific sequence is embedded in the frequency domain and BTS identification processing is performed in the frequency domain allowing the elimination of MIMO-OFDM inter-channel interference. BTS power estimation is performed based on the pilot channel for each MIMO-OFDM BTS. BTS selection is performed based on C/I ratio measurements.

The result is improvement of the synchronization and identification of the serving BTS in a severe multi-path channel and high interference environment by joint BTS synchronization and cell selection. Channel estimation may be performed on a combined common synchronization channel and dedicated pilot channel. Criteria are provided for cell switching and soft handoff by C/I estimation.

In the above example, the access has been performed based on the synchronization channel and pilot



channel embedded in the previously discussed preamble. More generally, the access can be performed with such channels embedded in any suitable manner within an OFDM symbol stream.

- 5           What has been described is merely illustrative of the application of the principles of the invention. Other arrangements and methods can be implemented by those skilled in the art without departing from the spirit and scope of the present invention.

We claim:

1. A MIMO-OFDM transmitter adapted to transmit a header symbol format in which sub-carriers of a header OFDM symbol are divided into a non-contiguous set of sub-carriers  
5 for each of a plurality of antennas, with each antenna transmitting the header OFDM symbol only on the respective set of sub-carriers.
2. A transmitter according to claim 1 wherein there are N antennas and a different set of sub-carriers separated  
10 by N sub-carriers is assigned to each of the plurality of antennas.
3. A transmitter according to claim 1 wherein the header symbols contain a multiplexed dedicated pilot channel on dedicated pilot channel sub-carriers and common  
15 synchronization channel on common synchronization channel sub-carriers for each of the plurality of antennas.
4. A transmitter according to claim 3 wherein the header OFDM symbols further contain multiplexed broadcasting sub-carriers for each of the plurality of antennas.
- 20 5. A transmitter according to claim 1, adapted to transmit a preamble having a prefix, followed by two identical OFDM symbols having said header OFDM symbol format.
6. A transmitter according to claim 5 wherein the  
25 prefix is a cyclic extension of the two identical OFDM symbols.
7. A transmitter according to claim 3 wherein the pilot channel sub-carriers have a BTS specific mapped complex sequence allowing efficient BTS identification.
- 30 8. A transmitter according to any one of claims 3 wherein the common synchronization channel is designed for fast and accurate initial acquisition.

9. A transmitter according to claim 3 wherein the common synchronization channel is used for course synchronization and fine synchronization and the pilot channel is used for fine synchronization.

5 10. A transmitter according to claim 3 wherein the common synchronization channel is used to transmit a complex sequence which is different for each transmit antenna of one transmitter, but which is common for respective transmit antennas of different transmitters within a communications  
10 network.

11. A transmitter according to claim 1 adapted to transmit OFDM frames beginning with said preamble, and having scattered pilots throughout a remainder of the OFDM symbols in each OFDM frame.

15 12. A transmitter according to claim 1 wherein during the preamble, for each of N transmit antennas, dedicated pilot channel sub-carriers are transmitted and common synchronization channel sub-carriers are transmitted and broadcasting channel sub-carriers are transmitted.

20 13. A transmitter according to claim 3 wherein the sub-carriers of the preamble OFDM symbols are organized as a repeating sequence of {dedicated pilot channel for each of N transmit antennas, common synchronization channel sub-carrier for each of N transmit antennas} arranged in a  
25 predetermined order.

14. A transmitter according to claim 4 wherein the sub-carriers of the preamble OFDM symbols are organized as a repeating sequence of {at least one dedicated pilot channel sub-carrier for each of N transmit antennas, at least one  
30 common synchronization channel sub-carrier for each of N transmit antennas, at least one broadcast channel sub-carrier} arranged in a predetermined order.

15. A MIMO-OFDM receiver adapted to receive a header symbol format in which sub-carriers of a header OFDM symbol are divided into a non-contiguous set of sub-carriers for each of a plurality of antennas, with each antenna  
5 transmitting the header OFDM symbol only on the respective set of sub-carriers.
16. A receiver according to claim 15 adapted to receive from N transmit antennas with a different set of sub-carriers separated by N sub-carriers assigned to each of  
10 the plurality of transmit antennas.
17. A receiver according to claim 15 wherein the header OFDM symbols contain multiplexed dedicated pilot channel sub-carriers and common synchronization channel sub-carriers for each of the plurality of transmit antennas.
- 15 18. A receiver according to claim 17 wherein the header OFDM symbols further contain multiplexed broadcasting carriers for each of the plurality of antennas.
19. A receiver according to claim 15 adapted to receive a preamble having a prefix, followed by two  
20 identical OFDM symbols having said header OFDM symbol format.
20. A receiver according to claim 15 wherein the dedicated pilot channel has a BTS specific mapped complex sequence, the receiver being adapted to perform BTS  
25 identification on the basis of the dedicated pilot channel.
21. A receiver according to claim 19 wherein the dedicated pilot channel have a BTS specific mapped complex sequence, the receiver being adapted to perform BTS identification on the basis of the dedicated pilot channel.
- 30 22. A receiver according to claim 21 wherein the header OFDM symbols contain multiplexed dedicated pilot channel sub-carriers and common synchronization channel sub-

carriers for each of the plurality of transmit antennas, the receiver being further adapted to perform course synchronization on the common synchronization channel by looking for a correlation peak between consecutive OFDM symbols which are identical.

23. A receiver according to claim 22 further adapted to perform fine synchronization on the basis of the common synchronization channel sub-carriers and/or the dedicated pilot channel sub-carriers.

10 24. A transmitter adapted to transmit a packet data frame structure comprising:

a superframe having a length corresponding to a synchronization period of a network;

15 the superframe containing a plurality of radio frames;

each radio frame containing a plurality of TPS (transmission parameter signalling) frames corresponding to an adaptive coding and modulation period;

20 each TPS frame containing a plurality of slots corresponding to an air interface slot size;

each slot containing a plurality of OFDM symbols, with the first two symbols of the first slot of the first TPS frame of each OFDM frame being used as header OFDM symbols.

25 25. A transmitter according to claim 24 wherein the header OFDM symbols have a header OFDM symbol format in which sub-carriers of a header OFDM symbol are divided into a non-contiguous set of sub-carriers for each of a plurality of antennas, with each antenna transmitting the header OFDM symbol only on the respective set of sub-carriers.

30

26. A transmitter according to claim 24 wherein the header OFDM symbols contain multiplexed pilot channel sub-carriers and common synchronization channel sub-carriers for each of the plurality of antennas.

5 27. A transmitter according to claim 24 wherein the header OFDM symbols further contain multiplexed broadcasting channel sub-carriers for each of the plurality of antennas.

28. A transmitter according to claim 24 adapted to transmit in a plurality of different modes by transmitting a  
10 different number of OFDM symbols per slot with an unchanged slot duration and with no change to the frame structure above the slot.

29. A transmitter according to claim 28 wherein modes with an increased number of OFDM symbols per slot are  
15 realized by shortening OFDM symbol duration, and shortening FFT size, but not changing sampling frequency.

30. A transmitter according to claim 24 adapted to transmit to a respective set of users for each TPS frame and to signal for each TPS frame which users should demodulate  
20 the entire TPS frame.

31. A receiver adapted to receive and process OFDM frames transmitted by the transmitter of claim 24.

32. A method of performing synchronization at an OFDM receiver comprising:

25 at each of at least one receive antenna, sampling a received signal to produce a respective set of time domain samples;

determining at least one course synchronization position;

30 at each of the at least one receive antenna:

a) for each of a plurality of candidate fine synchronization positions about one of said at least one course synchronization position:

- i) for each receive antenna  
5 positioning an FFT window to the candidate fine synchronization position and converting by FFT the time domain samples into a respective set of frequency domain components;
- ii) for each said at least one  
10 transmit antenna, extracting a respective received training sequence corresponding to the transmit antenna from the sets of frequency domain components;
- iii) for each transmit antenna,  
calculating a correlation between each respective received  
15 training sequence and a respective known transmit training sequence;
- iv) combining the correlations for  
the at least one transmit antennas to produce an overall correlation result for each candidate synchronization  
20 position;

b) determining a fine synchronization position from the plurality of correlation values;

combining the fine synchronization positions from the at least one receive antenna in an overall fine  
25 synchronization position.

33. A method according to claim 32 wherein a course synchronization position is determined for each receive antenna and used for determining the respective fine synchronization position.

30 34. A method according to claim 32 a course synchronization position is determined for each receive

antenna and an earliest of the positions is used determining the fine synchronization positions for all receive antennas.

35. A method according to claim 33 wherein the course synchronization position is determined in the time domain  
5 for at least one receive antenna by looking for a correlation peak between the time domain samples over two OFDM symbol durations.

36. A method according to claim 32 applied at an OFDM receiver having at least two antennas, combining the fine  
10 synchronization positions from the at least one receive antenna in an overall fine synchronization position comprises selecting an earliest of the fine synchronization positions.

37. A method according to claim 32 wherein:  
15 sampling a received signal to produce a set of time domain samples is done for at least three OFDM symbol durations;

determining at least one course synchronization position comprises performing a course synchronization in  
20 the time domain by looking for a correlation peak between the time domain samples received over two OFDM symbol durations to identify a course synchronization position by:

a) calculating a plurality of correlation values, each correlation value being a correlation  
25 calculated between a first set of time domain samples received during a first period having one OFDM symbol duration and a second set of time domain samples received during a second period immediately following the first period and having OFDM symbol duration, for each of a  
30 plurality of starting times for said first period;



b) identifying the course synchronization position to be a maximum in said plurality of correlation values.

38. A method according to claim 32 wherein:

5 combining the correlations for the at least one transmit antennas to produce an overall correlation result for each candidate synchronization position comprises multiplying together the correlations for the at least one transmit antenna for each candidate synchronization  
10 position.

39. A method according to claim 32 applied to a single transmit antenna single receive antenna system.

40. A method according to claim 32 wherein the training sequence is received on common synchronization  
15 channel sub-carriers.

41. A method according to claim 32 wherein the training sequence is received during an OFDM frame preamble.

42. A method according to claim 32 wherein the training sequence is received on dedicated pilot channel  
20 sub-carriers.

43. A method according to claim 42 wherein the training sequence is received during an OFDM frame preamble.

44. An OFDM receiver comprising:

at least one receive antenna;

25 for each said at least one receive antenna, receive circuitry adapted to sample a received signal to produce a respective set of time domain samples;

a course synchronizer adapted to determine at least one course synchronization position;

a fine synchronizer comprising at least one FFT, at least one correlator and at least one combiner, adapted to, at each of the at least one receive antenna:

- a) for each of a plurality of candidate  
5 fine synchronization positions about one of said at least one course synchronization position:
    - i) for each receive antenna  
position an FFT window to the candidate fine synchronization position and convert by FFT the time domain samples into a  
10 respective set of frequency domain components;
    - ii) for each said at least one transmit antenna, extract a respective received training sequence corresponding to the transmit antenna from the sets of frequency domain components;
    - 15 iii) for each transmit antenna, calculate a correlation between each respective received training sequence and a respective known transmit training sequence;
    - iv) combine the correlations for  
20 the at least one transmit antennas to produce an overall correlation result for each candidate synchronization position;
  - b) determine a fine synchronization position from the plurality of correlation values;  
25 the receiver being further adapted to combine the fine synchronization positions from the at least one receive antenna in an overall fine synchronization position.
45. A receiver according to claim 44 having at least two receive antennas, adapted to combine the fine  
30 synchronization positions from the at least one receive antenna in an overall fine synchronization position by selecting an earliest of the fine synchronization positions.

46. A receiver according to claim 44 adapted to combine the correlations for the at least one transmit antennas to produce an overall correlation result for each candidate synchronization position by multiplying together  
5 the correlations for the at least one transmit antenna for each candidate synchronization position.

47. A receiver according to claim 44 adapted to receive the training sequence on common synchronization channel sub-carriers.

10 48. A receiver according to claim 44 adapted to receive the training sequence on dedicated pilot channel sub-carriers.

49. A method of performing fine synchronization comprising:

15 at each at least one receive antenna receiving OFDM symbols containing a respective received frequency domain training sequence for each of at least one transmit antenna;

performing fine synchronization in the frequency  
20 domain by looking for maximum correlations between known frequency domain training sequences and the received frequency domain training sequences.

50. A method of transmitting signals enabling fine synchronization comprising:

25 from each of at least one transmit antenna, transmitting OFDM symbols containing a respective frequency domain training sequence.

51. A method according to claim 50 wherein a different frequency domain training sequence is transmitted by each  
30 transmit antenna, but the same frequency domain training sequence is transmitted by corresponding antenna of other transmitters.

52. A method of performing cell selection at an OFDM receiver comprising:

at each of at least one receive antenna, sampling a received signal to produce a respective set of time domain  
5 samples;

determining at least one course synchronization position;

at each of the at least one receive antenna:

a) performing a frequency domain  
10 correlation between at least one received common synchronization sequence extracted from common synchronization channel sub-carriers in the received signal and a corresponding common synchronization sequence of a respective plurality of transmit antennas to identify a  
15 plurality of candidate correlation peaks;

b) selecting the M strongest correlation peaks for further processing;

c) at each correlation peak, reconvert time domain samples into frequency domain components and  
20 processing pilot channel sub-carriers, these containing transmitter specific information, to identify a transmitter associated with each correlation peak;

d) determining a C/I or similar value for each transmitter thus identified;

25 selecting the transmitter having the largest C/I determined for any of the at least one receive antenna.

53. A method according to claim 52 wherein performing a frequency domain correlation between at least one received common synchronization sequence extracted from common  
30 synchronization channel sub-carriers in the received signal and a corresponding common synchronization sequence of a

respective plurality of transmit antennas to identify a plurality of candidate correlation peaks comprises:

- a) for each of a plurality of candidate fine synchronization positions about one of said at least one course synchronization position:
  - i) for each receive antenna positioning an FFT window to the candidate fine synchronization position and converting by FFT the time domain samples into a respective set of frequency domain components;
  - ii) for each of at least one common synchronization sequence, each common synchronization sequence having been transmitted by a transmit antenna of each of at least one transmitter, extracting a respective received training sequence corresponding to the transmit antennas from the sets of frequency domain components;
  - iii) for each of the at least one common synchronization sequence, calculating a correlation between each respective received common synchronization sequence and a respective known common synchronization sequence;
  - iv) combining the correlations to produce an overall correlation result for each candidate synchronization position;
- b) determining at least one peak in the correlations, each said at least one peak being local maxima in the correlations.

54. A method according to claim 53 further comprising:

- reconverting time domain samples into frequency domain components based on the fine synchronization position of the selected transmitter and performing a further fine

synchronization based on a dedicated pilot channel for that transmitter.

55.           A method according to claim 54 applied to a MIMO-OFDM frame format having a header symbol format in which  
5 subcarriers of a header symbol are divided into a non-contiguous set of subcarriers for each of a plurality of antennas, with each antenna transmitting header symbols only on the respective set of sub-carriers, and wherein the header symbols contain multiplexed pilot channel sub-  
10 carriers and common synchronization channel sub-carriers for each of the plurality of antennas, the frame beginning with two identical header OFDM symbols during which contents of the pilot channel sub-carriers are repeated and contents of the synchronization channel sub-carriers are repeated, the  
15 common synchronization channel sub-carriers carrying a complex sequence which is different for respective antenna of one base station and being common across multiple base stations, and contents of the dedicated pilot channel sub-carriers being at least locally unique to a particular base  
20 station.

56.           A method according to claim 52 further comprising:  
for transmitter switching, averaging the C/I or similar value over a time interval for each transmitter thus identified, and at the end of the time interval instigating  
25 a transmitter switch to the transmitter with the largest average C/I or similar value if different from a currently selected transmitted.

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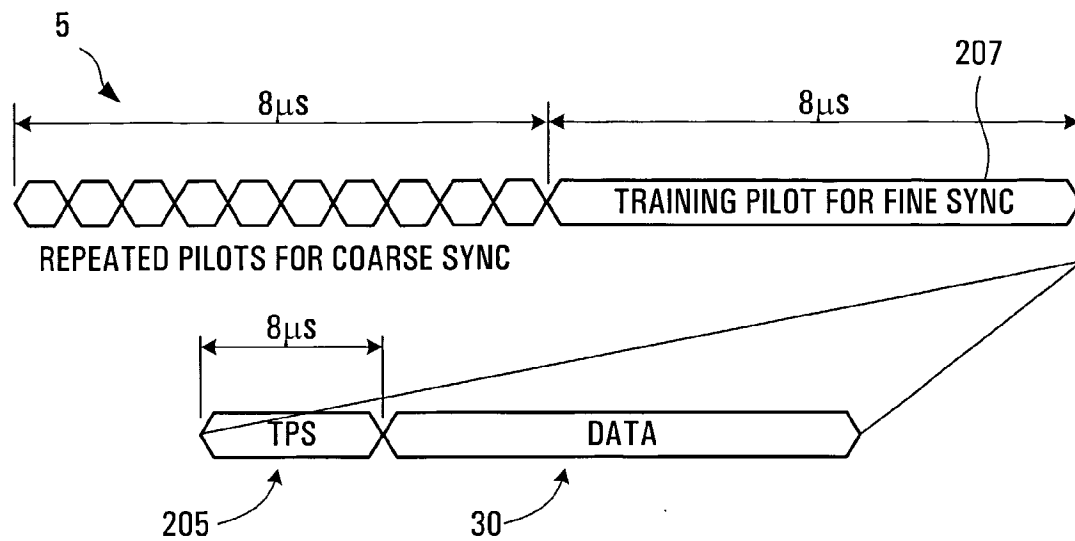


FIG. 1A

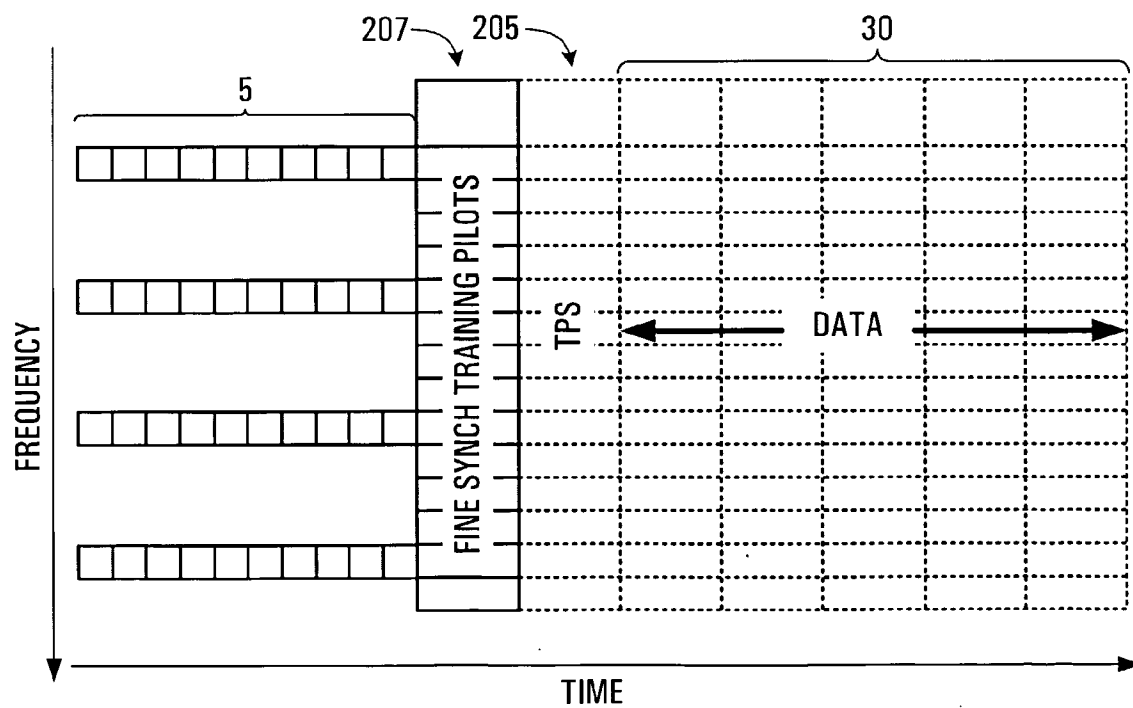


FIG. 1B

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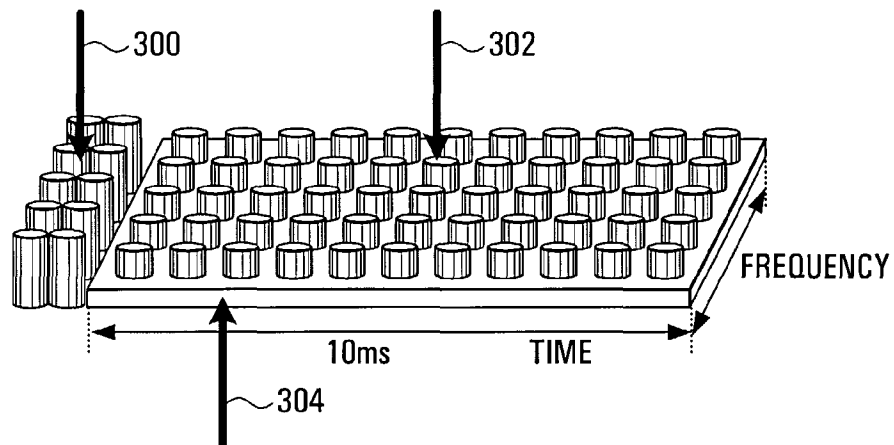


FIG. 2A



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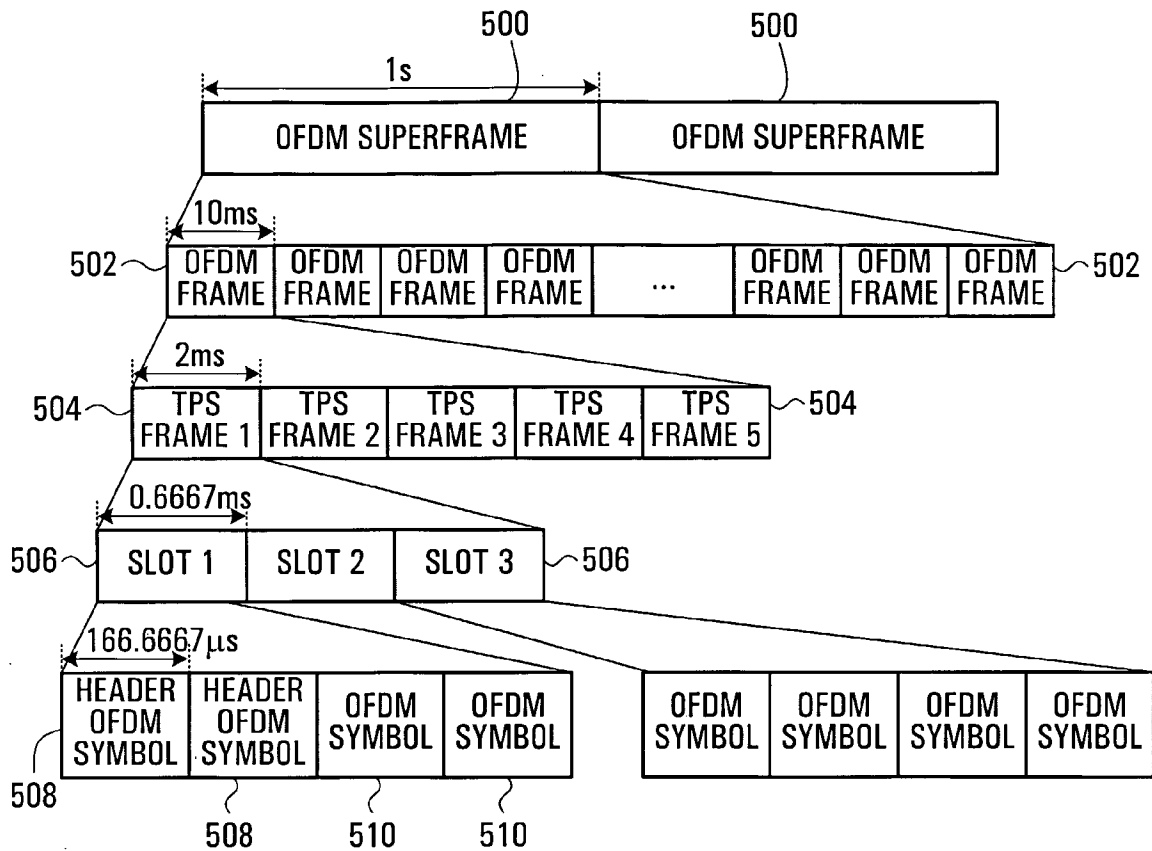


FIG. 2B

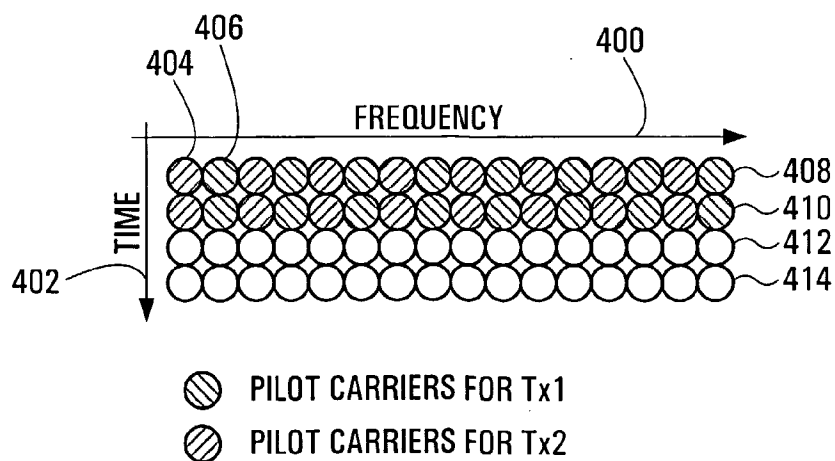


FIG. 2

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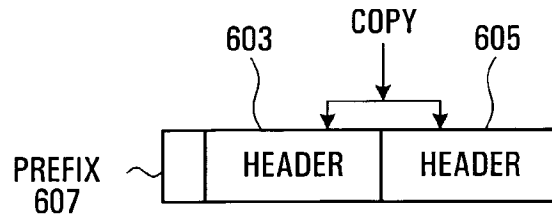


FIG. 4

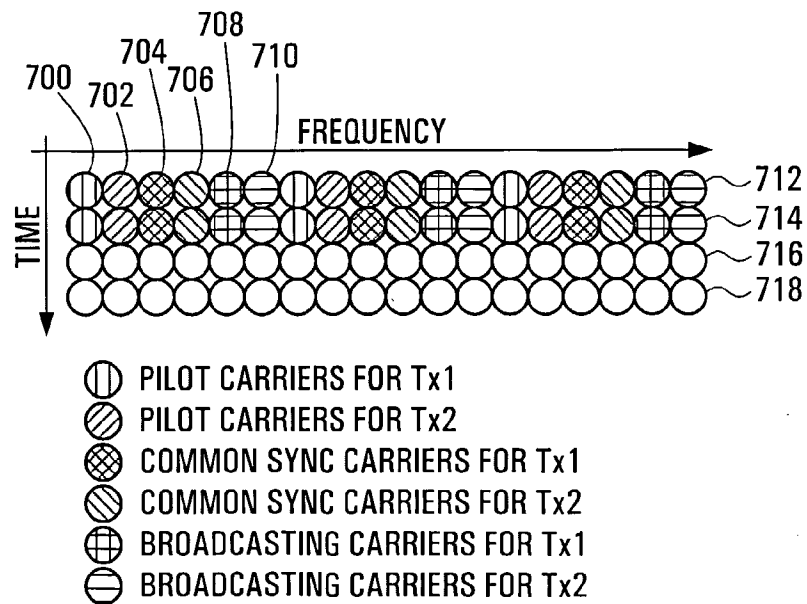


FIG. 5

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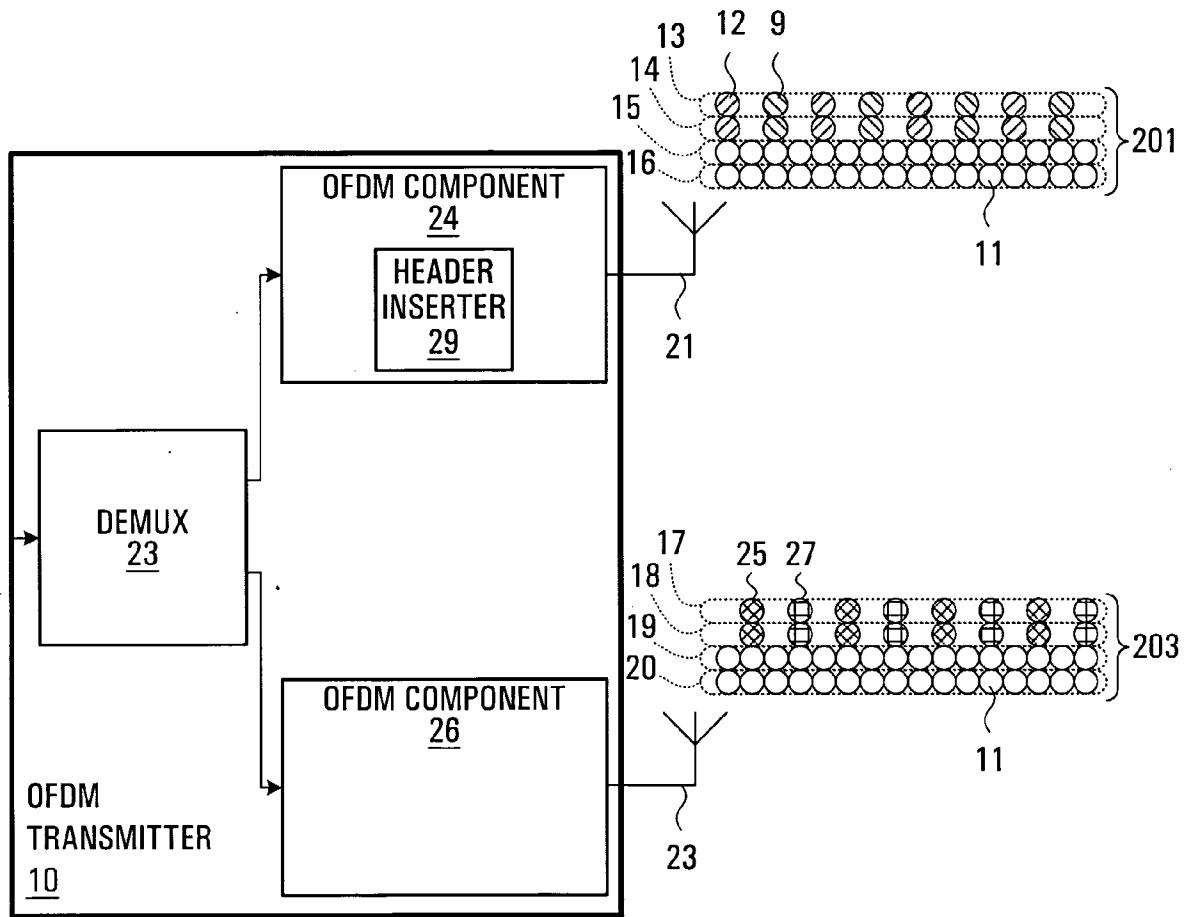


FIG. 6

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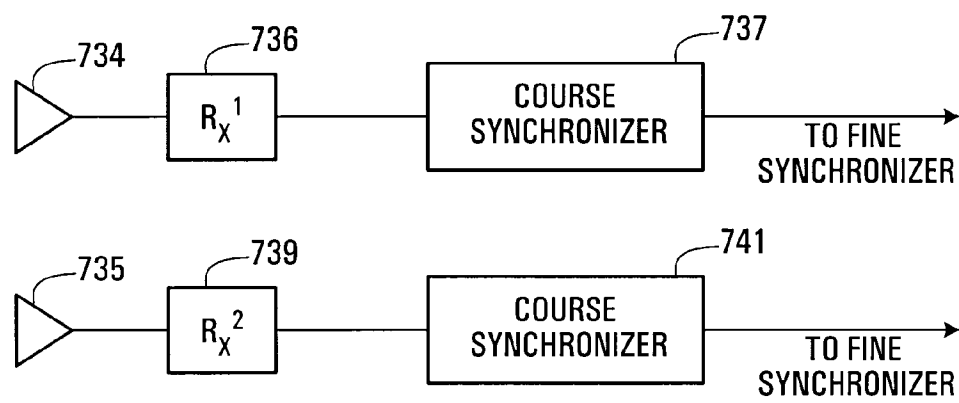


FIG. 7A

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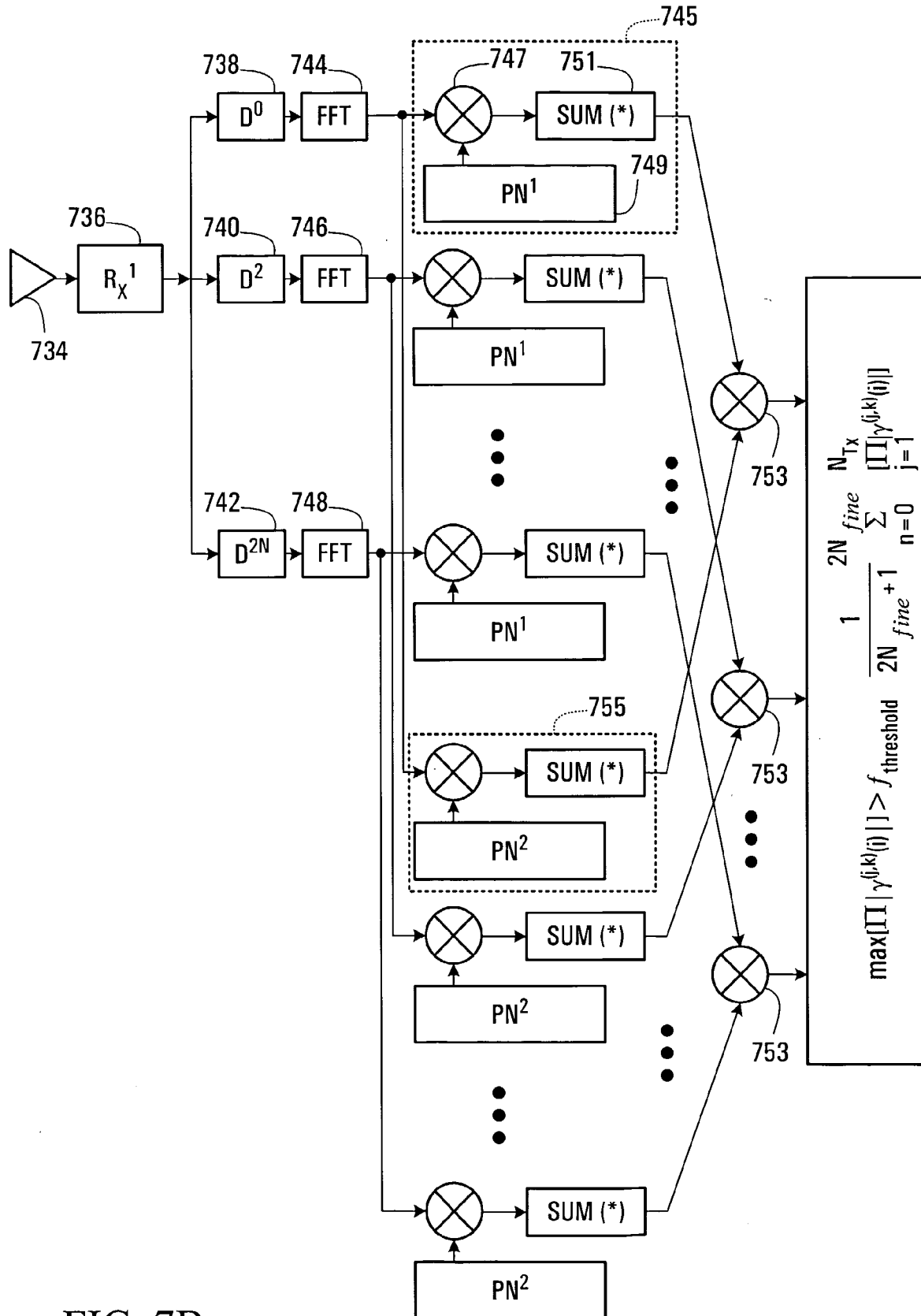


FIG. 7B

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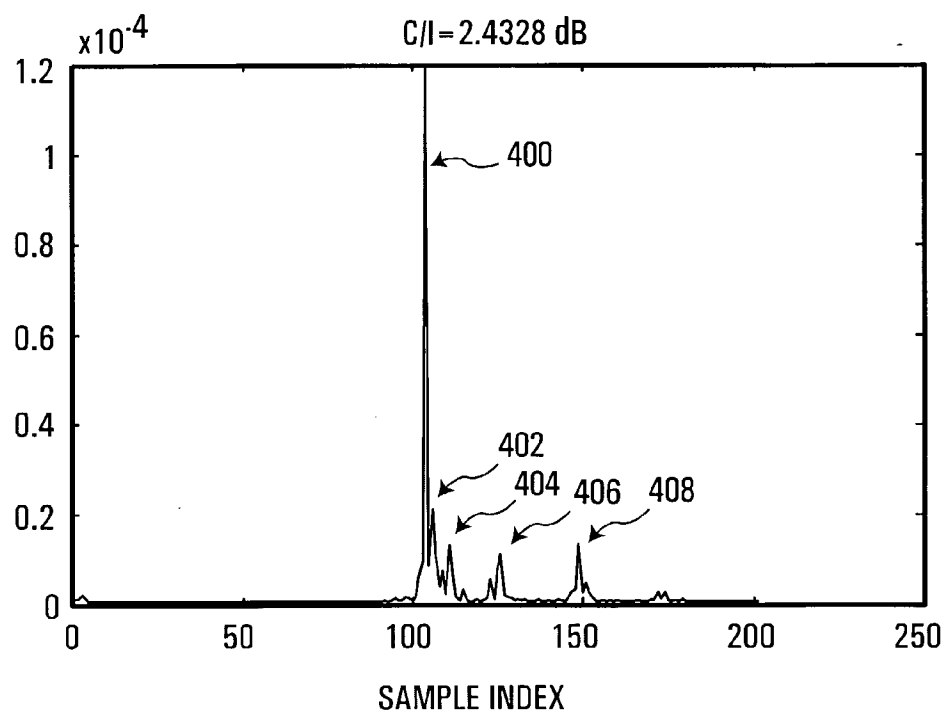


FIG. 8

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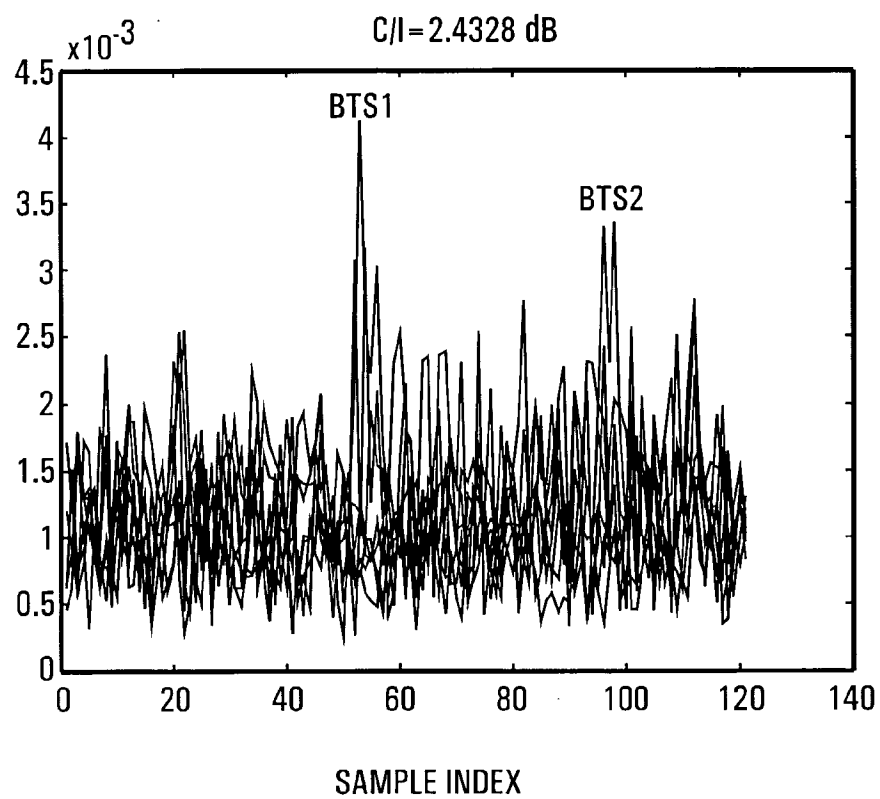


FIG. 9

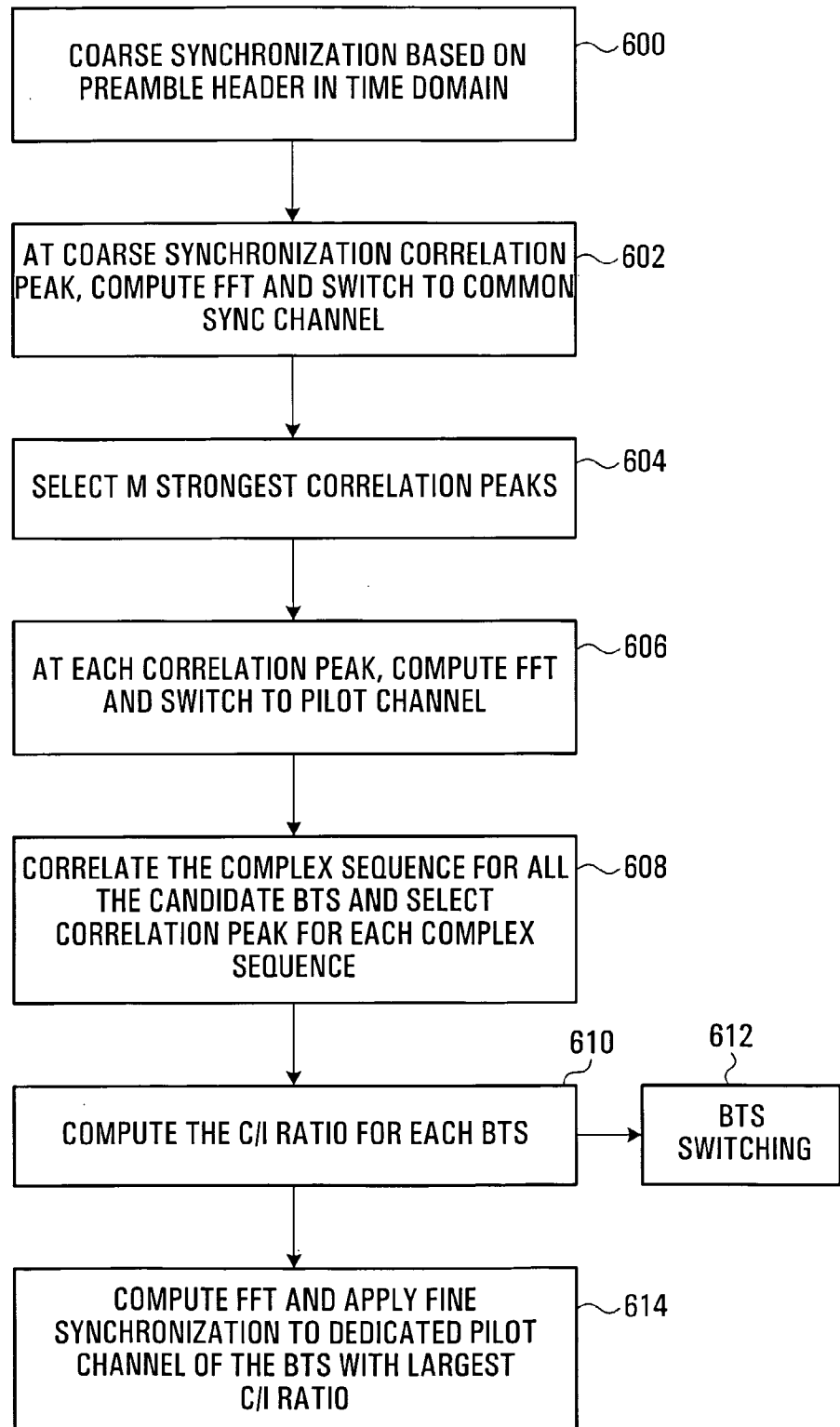
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FIG. 10